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Natural Disasters: Some Empirical and Economic Considerations

G. Thomas Sav

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National Bureau of Standards
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

PREFACE

This study was conducted for the Office of Federal Building Technology in the Center for Building Technology, Institute for Applied Technology, National Bureau of Standards. Dr. Charles Culver and Mr. Samuel Kramer, both of that Office, provided initial direction for the study. Dr. Harold E. Marshall, Building Economics Section, contributed valuable economic skills and editorial comments throughout the study. Dr. Peter F. Colwell, also of the Building Economics Section, was extremely helpful in his review of the paper.

Appreciation is extended for providing significant data for this study to the American Red Cross, Washington, D.C.; the Federal Disaster Assistance Administration, Washington, D.C.; and the National Climatic Center, Asheville, N.C.

ABSTRACT

This study examines the extent of some of the losses resulting from natural disasters. An estimate of these losses is necessary in order to determine the potential benefits that might be realized from mitigating the negative economic impacts from natural disasters. Absolute and relative losses resulting from hurricanes, floods, earthquakes and tornadoes are examined. These data will help individuals, communities, and the Federal government make better decisions as to how and to what extent protection against disasters should be provided. The application of benefit-cost analysis for choosing the optimal level of protection against disasters is also discussed. Recommendations are made for further research in determining the economic feasibility of various techniques designed to mitigate the losses from disasters.

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1. INTRODUCTION

Natural disasters cost the United States about a billion dollars each year. More recently, these costs have exceeded the billion dollar level. In 1973 more than $1.2 billion worth of property was damaged as a result of natural disasters.[1] During 1972 estimated property damages amounted to $3.5 billion.[2] Such losses tend to represent the cost of restoring physical structures to their pre-disaster condition. However, they do not measure the full economic impact of natural disasters. Dollar losses usually fail to include the losses in human lives, losses due to human suffering, losses in productivity, losses in the tax base and tax revenues, and social disruptions resulting from disasters.

The real property losses due to natural disasters show an increasing trend over time.[3] Figure 1.1 shows the annual number of disasters which caused losses (on insured property) in excess of $1,000,000. An upward trend in the number of occurrences causing such losses is also indicated by Figure 1.1. Several factors may be responsible for this trend. First a demographic shift to disaster prone areas increases potential losses. Second, changing property values are reflected in any time series comparison of nominal dollar property losses. Another factor that might be responsible for increasing losses would be an increase in the frequency and severity of natural phenomena; e.g., hurricanes, floods, earthquakes, and tornadoes. A fourth possibility is a reduction in society's level of disaster preparedness relative to its increasing need for disaster protection.

Chapter 2 catalogues past losses from natural disasters. Four major types of natural phenomena are examined: hurricanes, floods, earthquakes, and tornadoes. Because existing sources have not been consistent in reporting past losses for a particular type of disaster or among different types of disasters, this study is a selective survey of losses rather than an extensive analysis of the economic impacts resulting from natural disasters.

A uniform approach is taken to describe the losses produced by each of the four natural phenomena. First, the distribution of dollar losses with respect to time is discussed. Next, an effort is made to extract a trend from the annual dollar losses and physical losses (e.g., lives lost, families suffering loss, and buildings destroyed). Thirdly, comparison is made of the losses incurred during several severe disasters in the United States. Finally, there is a discussion of the impact that a single natural disaster generates. Examples are provided for hurricanes, floods, and earthquakes.

In Chapter 3, benefit-cost analysis is discussed as a method of determining the most efficient level of disaster protection; i.e., the level of protection that maximizes society's net benefits.

The final chapter compares the relative losses of different types of disasters and discusses possible techniques for mitigating losses due to natural disasters. Recommendations for further research are made on the basis of the conclusions drawn from this paper.

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[1] Federal Disaster Assistance Administration, News Release HUD No. 74-DA-1, January 4, 1974.

[2] Ibid.

[3] Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 12.

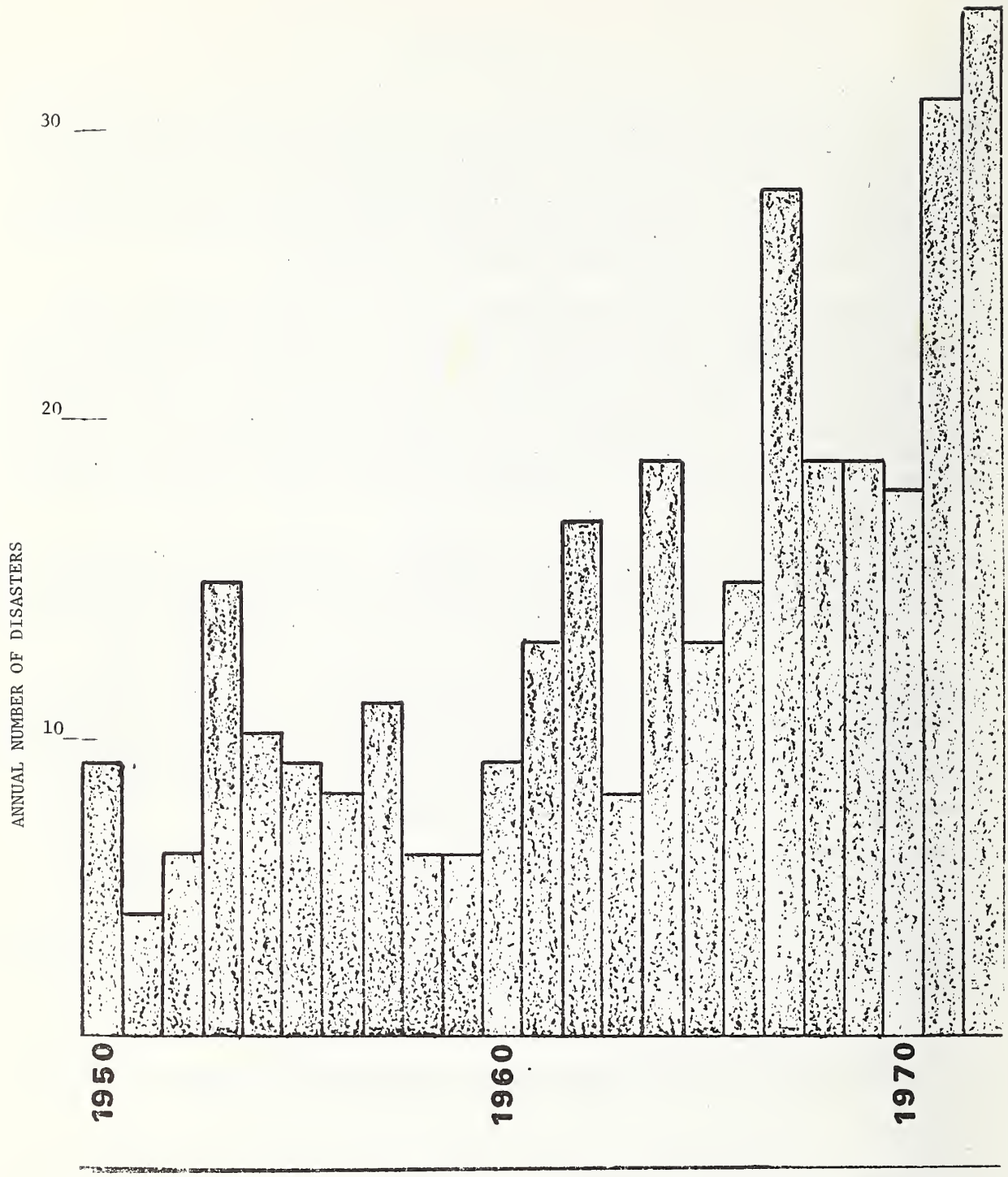

Figure 1.1 Annual number of disasters causing losses on insured property in excess of $1,000,000.

Source: Don G. Friedman, "Prospective View of Natural Disasters in the United States," a paper presented at The System Safety Society Symposium, July 18, 1973.

2. COSTS OF NATURAL DISASTERS

2.1 Hurricanes

The destruction caused by hurricanes is the result of high winds, of storm surges which are themselves produced by high winds, and of flooding produced by heavy rainfall. For days after a hurricane has passed, its flood producing rains may continue to take lives and destroy property. The destruction resulting from these floods may be proportionately greater than that due to the winds produced during the hurricane. For example, Hurricane Agnes produced devastating floods while its winds were relatively less damaging.

The real property losses resulting from hurricanes have been increasing through time. For the period 1934-1964 Dacy and Kunreuther have estimated that hurricane damages have increased annually at a rate of 4.5%; they also report that the annual rate of increase since 1950 has been 10.5%.[1] Table 2.1 shows that the property losses for the 1965-1969 period ($3,091 million) increased by more than 96% ($1,515 million) over the previous five year period losses ($1,576 million). Figure 2.1 depicts this trend by five-year intervals for the period 1915-1969 (Table 2.2 shows a year by year account of these losses and the number of lives lost, 1915-1970). Dollar damages are measured in constant 1957-1959 dollars. One cause of the upward trend is probably the rapid economic development of the areas subject to hurricane damage.

In addition to increasing property damages there may be an increasing potential for the loss of lives as the population density in hurricane prone areas increases (Figure 2.2 gives an indication of hurricane prone areas by showing the paths of six severe hurricanes, 1964-1970). However, Figure 2.1 indicates deaths due to hurricanes have exhibited a decreasing trend over the years 1900-1969. This could be attributed to advancements in hurricane watch and warning systems and their advancements in the dissemination of information.

The numbers of lives lost and the damages resulting from individual hurricanes have been anything but stable. Fluctuations in the magnitudes of impact from specific hurricanes is evidenced in Table 2.3. Damages range from $170,000 and no lives reported lost (September 21-29, 1917) to $1,420,700 in damages and 256 lives lost (August 5-22, 1969).[2]

Table 2.4 shows numbers of deaths, numbers of people injured, numbers of people given emergency care, and numbers of people suffering losses as a result of hurricanes. These losses have not been monetized. However, one could attempt to estimate the implicit monetary value due, for example, to losses of human lives. One interpretation of the social cost of a human life (human capital) is the net loss in the productive value which that individual would provide to society over his expected remaining life span. However, this cost does not reflect the pain and suffering or psychological impact which premature deaths have on relatives and friends. Nor does it show, for example, the loss in a community's tax base due to deaths, injuries, or illnesses.

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[1] Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 17.

[2] To determine the real value of dollar losses over time, a price index based on the real purchasing power of a dollar in a given year should be used to inflate (or deflate) nominal dollar values for other years.

TABLE 2.1

LOSS OF LIFE AND PROPERTY DAMAGE IN THE UNITED STATES DUE TO HURRICANES, BY FIVE-YEAR PERIODS, 1925-1969, AND 1970

Years	Property Loss ($1,000,000)	Number of Lives Lost
1925-1929	133	2114
1930-1934	51	80
1935-1939	314	1026
1940-1944	222	149
1945-1949	298	67
1950-1954	802	217
1955-1959	539	660
1960-1964	1576	175
1965-1969	3091	412
1970	454	11

Source: Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 6, data for 1925-1964; and Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D. C.: Government Printing Office, January 1972), p. 46, data for 1965-1969, and 1970.

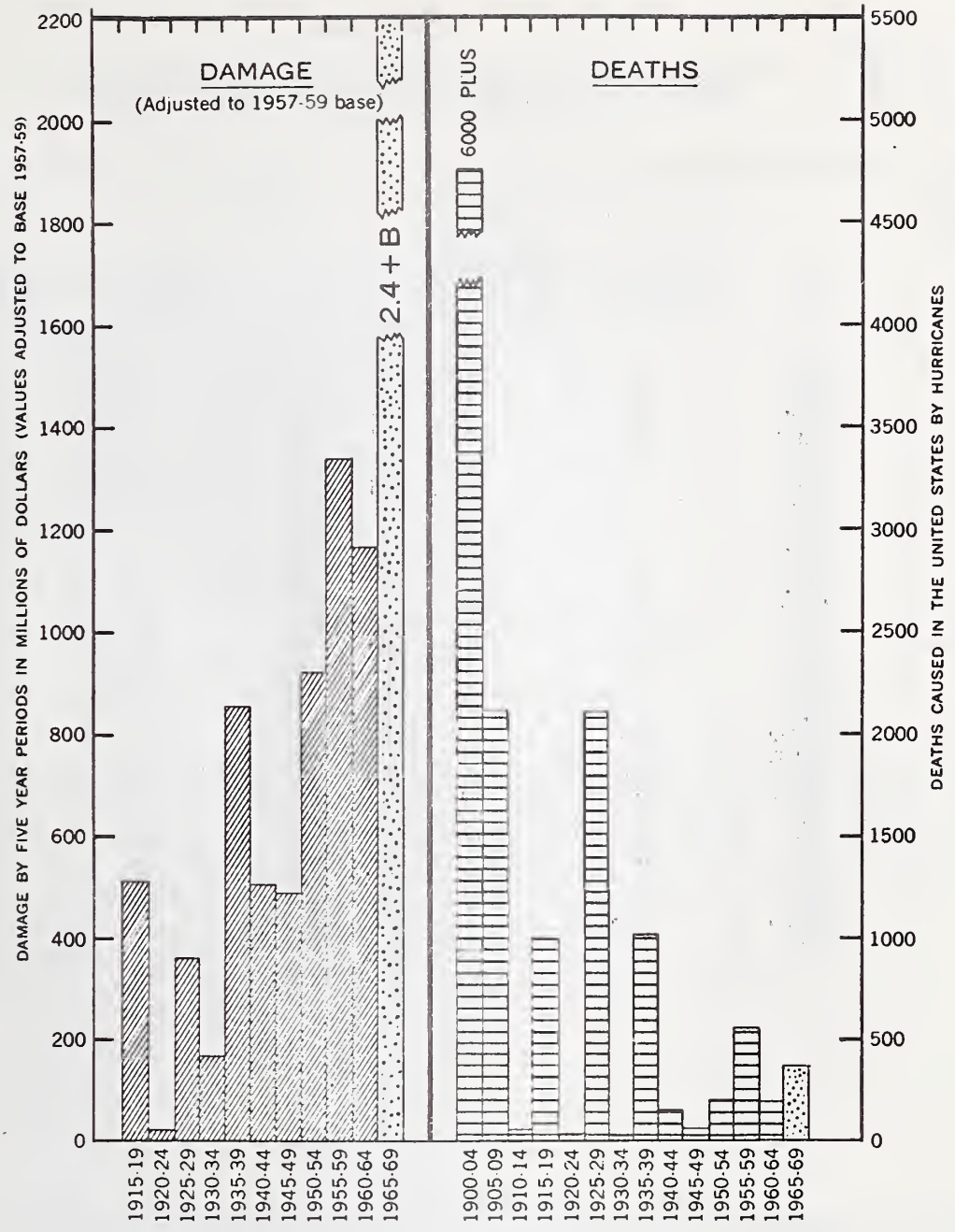


Figure 2.1 Trends of damages and deaths due to hurricanes in the United States

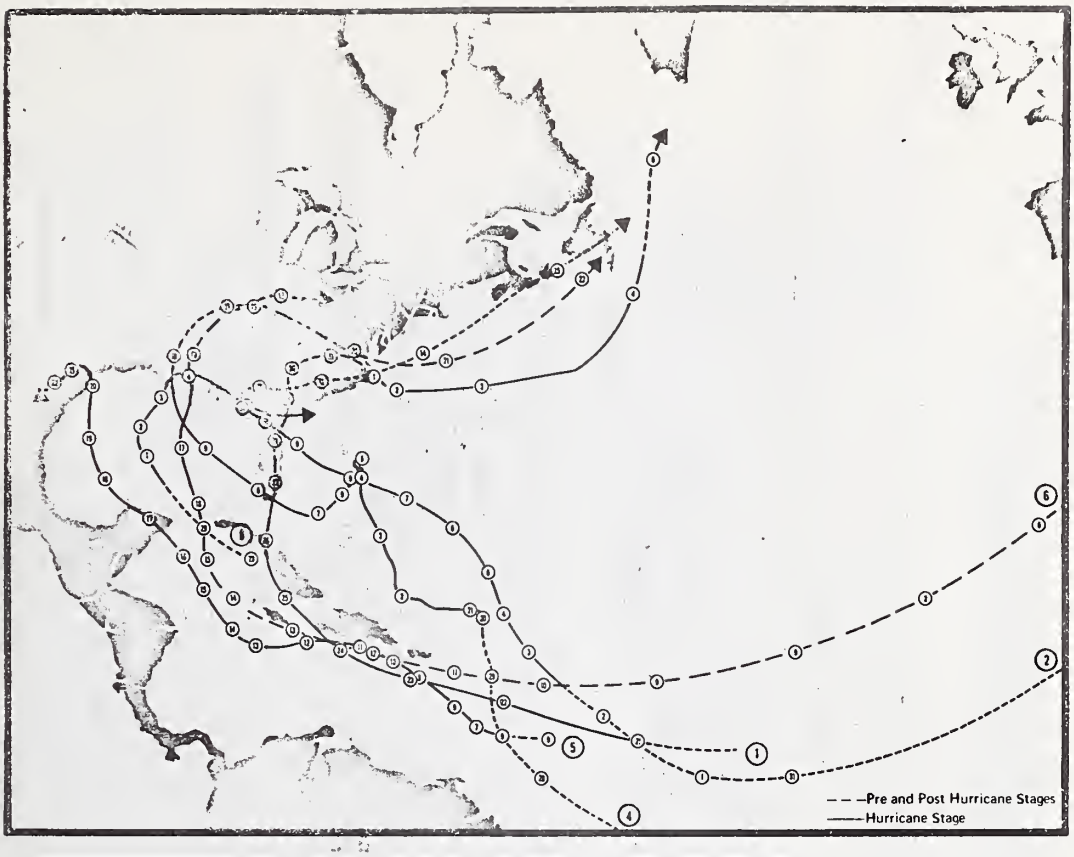
Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office; January 1972), p. 42.

TABLE 2.2

ESTIMATED LIVES LOST AND DAMAGES IN THE UNITED STATES DUE TO NORTH ATLANTIC TROPICAL CYCLONES, BY YEAR, 1915-1970

Year	Number of Lives Lost	Damages ($1,000,000)	Year	Number of Lives Lost	Damages ($1,000,000)
1915	600	63.0	1943	16	16.8
1916	107	33.3	1944	64	165.0
1917	5	0.2	1945	7	80.1
1918	34	5.0	1946	0	5.2
1919	287	22.0	1947	53	135.8
1920	2	3.0	1948	3	18.4
1921	5	3.0	1949	4	58.8
1922	0	0	1950	19	35.9
1923	0	Minor	1951	0	2.0
1924	2	Minor	1952	3	2.8
1925	6	Minor	1953	2	6.2
1926	269	106.5	1954	193	755.5
1927	0	0	1955	218	984.5
1928	1,836	25.0	1956	21	26.5
1929	3	0.7	1957	395	152.1
1930	0	Minor	1958	2	11.2
1931	0	0	1959	24	23.1
1932	0	0	1960	65	370.4
1933	63	46.7	1961	46	331.0
1934	17	4.8	1962	4	1.1
1935	414	11.5	1963	10	13.0
1936	9	2.3	1964	49	515.2
1937	0	Minor	1965	75	1,446.0
1938	600	300.2	1966	54	15.0
1939	3	Minor	1967	18	200.0
1940	51	4.7	1968	9	10.0
1941	10	7.7	1969	256	1,420.0
1942	8	27.1	1970	11	454.0
			Total	5,953	7,922.3

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D. C.: Government Printing Office, January 1972), p. 46.



DATES OF HURRICANE	AREAS MOST AFFECTED	DEATHS (U.S. only)	DAMAGE BY CATEGORY
1. August 20-September 5, 1964 CLEO	Southern Florida, Eastern Virginia		8[a]
2. August 28-September 16, 1964 DORA	Northeastern Florida, Southern Georgia	5	8
3. September 28-October 5, 1964 HILDA	Louisiana	38	8
4. August 27-September 12, 1965 BETSY	Southern Florida, Louisiana	75	9
5. September 5-22, 1967 BEULAH	Southern Texas	15	8
6. August 14-22, 1969 CAMILLE	Mississippi, Louisiana, Alabama, Virginia, West Virginia	255 (68 missing 11-10-69)	9
7. July 30-August 5, 1970 CELIA[b]	Texas, New Mexico	11	8

Figure 2.2 Selected hurricane paths, deaths, and damages in the United States, 1964-1970

[a]Damage Categories: Category 8 -- $50 million to $500 million.
Category 9 -- $500 million to $5 billion.

[b]The track for Celia is not shown.

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office, January 1972), p. 47.

TABLE 2.3

LIVES LOST AND DAMAGES DUE TO HURRICANE WIND AND STORM SURGE HAZARDS
ALONG THE GULF AND SOUTH ATLANTIC COASTLINES, 1900-1970

Date	Lives Lost	Damages	Areas Affected
Aug 27-Sep 15, 1900	6000	30,000,000	Galveston, Texas
Sep 3-18, 1906	-	-	North Carolina
Sep 19-29, 1906	34	2,000,000	15.0 ft. tides at Coden, Alabama
Oct 11-22, 1906	164	-	Miami, Florida
Jul 13-22, 1909	41	2,000,000	Tide 10.0 ft. at Galveston, Texas
Sep 10-21, 1909	350	5,000,000	Tides 15.0 ft. at Timbalier Bay, Louisiana
Oct 6-13, 1909	15	1,000,000	Southern Florida
Oct 9-23,1910	30	365,000	Wind 125mph, Sand Key, Fla., tide 15.0 ft. Key West
Aug 23-30, 1911	17	-	Charleston, South Carolina
Aug 5-23, 1915	275	50,000,000	Wind 120mph at Galveston, Texas, tide 16.1 ft.
Sep 22-Oct 1, 1915	275	13,000,000	Tide 11.8 ft. at Bay St. Louis, Mississippi
Jun 29-Jul 10, 1916	4	3,000,000	Wind 107mph at Mobile, Ala., Tide 11.9 ft.
Aug 12-19, 1916	20	1,800,000	Wind 90mph Corpus Christi, Texas, tide 5.9
Oct 12-19, 1916	-	-	Wind 128mph at Mobile, Alabama
Sep 21-29, 1917	-	170,000	Wind 125mph at Pensacola,tide 7.8 ft.at Ft.Barancas, Fla.
Aug 1-6, 1918	34	5,000,000	Wind 125mph at Sulphur, Louisiana
Sep 2-15, 1919	900	22,000,000	Wind 110mph at Key West,Fla.,tides 16.0 ft.at CorpusChristi
Oct 20-29, 1921	6	3,000,000	Tide 11.0 ft. at Ponta Rassa, Florida
Aug 22-27, 1926	25	4,000,000	Tide 15.0 ft. at Terre Bonne Parish, Louisiana
Sep 11-22, 1926	243	112,000,000	Wind 138mph Miami, tide 13.2 ft. Miami
Sep 6-20, 1928	2136	76,000,000	Tide 9.8 ft. at Fort Pierce, Florida
Sep 22-Oct 4, 1929	3	800,000	Wind 150mph-Key Largo, Fla.,tide 10.2 ft.-Perrine,Fla.
Aug 11-14, 1932	40	7,500,000	Wind 100mph-Columbia, Texas
Aug 17-20, 1933	-	21,000,000	North Carolina and areas north
Aug 28-Sep 5, 1933	40	12,000,000	Wind 80mph-Brownsville,Tex.,tide 15.0 ft.-Brownsville
Aug 31-Sep 7, 1933	2	4,100,000	Wind 125mph-Jupiter, Florida

TABLE 2.3 (continued)

Date	Lives Lost	Damages	Areas Affected
Sep 8-21, 1933	21	$ 1,000,000	Wind 76mph at Cape Hatteras, North Carolina
Aug 29-Sep 10, 1935	408	6,000,000	Wind 200mph-Florida Keys, tide 20 ft.-Long Key
Oct 30-Nov 8, 1935	19	5,500,000	Wind 75mph at Miami, Florida
Sep 8-25, 1936	2	1,600,000	Wind 80mph at Cape Hatteras, North Carolina
Aug 2-10, 1940	-	1,800,000	Wind 82mph, tide 14.5 ft.-Jennings, Louisiana
Aug 5-15, 1940	34	7,000,000	Tide 10.7 ft. at Charleston, South Carolina
Sep 16-25, 1941	4	6,000,000	Wind 83mph, tide 11.0 ft.-Matagorda, Texas
Oct 3-14, 1941	5	700,000	Wind 123mph, Miami, Florida, tide 8.0 ft.
Aug 21-31, 1942	8	26,500,000	Wind 120mph, Port Lavaca, tide 14.7 ft. Matagorda
Sep 9-16, 1944	390	100,000,000	North Carolina to New New England
Oct 12-23, 1944	18	60,000,000	Wind 120mph-Dry Tortugas, Fla., tides 11.0 ft. Naples
Aug 24-29, 1945	3	20,100,000	Wind 135mph-Port Lavaca, Fla., tide 14.5 ft.
Sep 11-20, 1945	26	54,100,000	Wind 196mph-Homestead, Fla., tides 13.7 ft.
Oct 4-14, 1946	-	7,200,000	Wind 80mph-Fort Myers, tides 5.1 Punta Gorda
Sep 4-21, 1947	51	110,000,000	Wind 155mph-Hillsboro, Fla.,Tide 21.6 ft.Clewiston, Fla.
Oct 9-16, 1947	1	23,000,000	Wind 95mph-Savannah, Georgia
Sep 18-25, 1948	3	17,500,000	Wind 122mph-Key West,Fla.,tide 19.0 ft. Canal Point,Fla.
Oct 3-15, 1948	11	5,000,000	Wind 100mph-Florida Keys,Fla.,tide 6.2 ft. Homestead
Aug 23-31, 1949	2	52,000,000	Wind 153mph-Jupiter,Fla.,Tide 24.0 ft. Belle Glade
Sep 27-Oct 6, 1949	2	7,000,000	Wind 135mph-Freeport,Tex; tides 11.4 ft. Harrisburg
Sep 1-9, 1950	2	3,300,000	Wind 125mph-Cedar Key, Fla., tide wrecked Cedar Key
Oct 13-19, 1950	4	28,000,000	Wind 150mph-Miami,Fla.,tide 19.3 ft. Clewison, Fla.
Oct 5-18, 1954	98	251,600,000	Wind 150mph-Cape Fear, N.C., tide 17.0 ft.Wilmington,N.C.
Aug 3-14, 1955	-	40,000,000	Wind 100mph-Ft.Macon, N.C., tide 8.0 ft. Nags Head
Aug 7-21, 1955	-	65,000,000	Wind 74mph-Wilmington, N.C., tide 8.0 ft. Wilmington
Sep 10-23, 1955	7	88,000,000	North Carolina
Sep 21-30, 1956	15	24,900,000	Wind 100mph-Grand Isle, La., tide 10.0 ft.
Jun 25-28, 1957	390	150,000,000	Wind 180mph-Oil rig,La.,tide 13.9 ft.Oak Grove Ridge,La.
Sep 21-Oct 3, 1958	-	11,200,000	Wind 160mph-Cape Fear, N.C., tide 7.5 ft.
Sep 20-Oct 2, 1959	22	14,000,000	Wind 175mph-Beaufort, N.C., tide 12.0 ft.

TABLE 2.3 (continued)

Date	Lives Lost	Damages	Areas Affected
Aug 29-Sep 13, 1960	50	$426,000,000	Wind 200mph-Fla.Keys,tide 13.0 ft.,Florida to New England
Sep 3-15, 1961	46	408,200,000	Wind 175mph-Port Lavaca, Texas; tide 16.6 ft.
Aug 20-Sep 5, 1964	3	128,500,000	Wind 135mph-Miami, Florida; tide 5.5 ft.
Aug 28-Sep 16, 1964	5	250,000,000	Wind 125mph-St.Augustine,Fla.,tide 14.0 ft.Brunswick, Ga.
Sep 28-Oct 5, 1964	38	125,000,000	Wind 135mph-Franklin, La.,tide 10,0 ft. Point-au-Fer, La.
Aug 27-Sep 12, 1965	75	1,420,500,000	Wind 165mph-Fla.& La.,tide 15.2 ft.Pointe-a-la-Hache, La.
Sep 21-Oct, 1966	48	5,000,000	Wind 165mph-Big Pine Key, Fla., tide 5.0 ft.
Sep 5-22, 1967	15	200,000,000	Wind 120mph-Raymondville, Texas, tide 18.0 ft.Padre Island
Aug 5-22, 1969	256	1,420,700,000	Wind 135mph-Columbia, Miss.,tide 24.6 ft. Pass Christian
Jul 31-Aug 5, 1970	11	453,000,000	Wind 161mph-Corpus Christi, Texas, tide 9.2 ft.

Source: Don G. Friedman, "Prospective View of Natural Disasters in the United States" (paper presented at the System Safety Society Symposium, July 18, 1973), Table 2.

TABLE 2.4

DATA ON HURRICANES INVOLVING MORE THAN FIVE FAMILIES

Year	Persons Killed	Persons With Injuries or Illnesses	Persons Given Emergency Mass Care	Total Number of Families Suffering Losses	Dwellings Destroyed	Dwellings Damaged
1959-1960	4	59	19,066	[a]	117	16,868
1960-1961	132	2,070	218,920	[a]	2,476	58,238
1961-1962	45	11,967	426,785	[a]	2,053	52,136
1962-1963	8	707	55,200	[a]	3,241	6,744
1963-1964	2	30	8,124	[a]	3	2,721
1964-1965	45	7,801	288,131	59,903	221	49,390
1965-1966	72	25,202	320,488	179,721	2,059	148,607
1966-1967	--	13	10,459	1,258	6	316
1967-1968	19	11,396	219,610	34,600	388	29,405
1968-1969	2	45	4,312	966	1	705
1969-1970	272	9,062	260,265	79,225	6,046	48,734
1970-1971	9	4,498	150,819	43,696	1,887[b]	34,442[b]
1971-1972	2	235	51,754	24,427	36[b]	24,258[b]

[a]Not reported.

[b]Including mobile homes.

Source: American National Red Cross, Highlights of Disaster Relief Services, Fiscal Year 1960, 1961, 1962, 1963, 1964, 1965, 1966; and Annual Summary of Disaster Services Activities, 1967, 1968, 1969, 1970, 1971, 1972.

Dollar values are not reported for the destruction and damage to dwellings shown in Table 2.4 The destruction or damage to a dwelling involves many cost categories. In addition to the replacement costs of the home and belongings, there are costs in inconvenience and discomfort that families experience in relocation and temporary housing.

Unemployed resources that result from natural disasters are also economic losses. Table 2.5 includes the numbers of unemployed human resources related to the Agnes hurricane (1972) for seven states. Associated with the individual loss of income from unemployment is a decrease in tax revenues for the community. This occurs at a time when increased tax revenues are needed to meet the increased demand for public revenues stemming from post disaster restoration activities.

To relieve pressure on local and state contributions for recovery from national disasters, the Federal government provides aid through the President's Disaster Fund, Federal Disaster Assistance Administration. Table 2.5 indicates the amounts obligated from the Fund for the restoration of public facilities following the Agnes hurricane.

A study of the physical damage caused by Hurricane Agnes was conducted by Dun and Bradstreet. The study reported that the damage to business and industry for Florida, Maryland, New York, Pennsylvania, and Virginia amounted to $600 million.[1] Since this figure excludes losses in production and sales, it can be considered an underestimate of total losses.

Table 2.6 lists some of the most destructive hurricanes in the United States for the period 1930-1972. Since 1965 the three most destructive hurricanes have caused nearly $6 billion in damages; Agnes contributed more than $3 billion of this total.

2.2 Floods[2]

There are approximately 50 million acres of land prone to flooding in the United States.[3] The distribution of losses, however, varies geographically. Figure 2.3 divides the United States into 14 major river systems and indicates the distribution of flood losses by system for the period 1925-1971. The total losses for the period amounted to $10.4 billion. The Missouri, North Atlantic, Ohio, and Pacific river systems experienced the bulk (71%) of flood losses. The Missouri river system alone accounted for nearly 25% of the total losses.

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[1] Executive Office of the President, Office of Emergency Preparedness, The Federal Response to Tropical Storm Agnes, A Report to the Senate Subcommittee on Public Works, Subcommittee on Disaster Relief, May 1973, p. 6.

[2] It is not feasible in this report to separate flood losses into losses resulting from river floods, hurricanes, and other natural phenomena. Therefore, there will be some double-counting of losses from the previous section.

[3] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol 3.(Washington, D.C.: Government Printing Office, January 1972), p. 7.

TABLE 2.5

SELECTED DATA FROM HURRICANE AGNES

State	Number of Lives Lost	Number Hospitalized for Injury or Illness	Amounts Obligated from the President's Disaster Fund for Agnes Recovery[a] ($)	Agnes Related Unemployment
Florida	8	36	1,384,078	164
Georgia	0	1	N.A.	N.A.
Maryland	20	6	10,873,101	12,508
New York	31	118	46,352,182	15,138
Pennsylvania	48	799	183,184,696	112,158
Virginia	13	9	13,812,557	15,409
West Virginia	0	1	1,165,051	63
TOTALS	122[b]	970[b]	258,107,45[c]	155,440

[a]As of April 9, 1973.

[b]Includes Washington, D.C.

[c]Includes Ohio.

Source: Executive Office of the President, Office of Emergency Preparedness, The Federal Response to Tropical Storm Agnes, A Report to the Senate Committee on Public Works, Subcommittee on Disaster Relief, May 1973, pp. 4, 43, 48.

TABLE 2.6

MOST DESTRUCTIVE HURRICANES IN THE UNITED STATES, 1930-1972

Hurricane	Year	Damage ($1,000,000)	Number of Deaths
Agnes	1972	3,097.8	117
Camille	1969	1,420.7	258
Betsy	1965	1,420.5	75
Diane	1955	831.7	184
Carol	1954	463.0	60
Celia	1970	453.8	11
Carla	1961	408.3	46
New England Storm	1938	387.1	600
Donna	1960	386.5	50
Hazel	1954	251.6	95

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data, National Summary 1972, Vol. 23, p. 62.

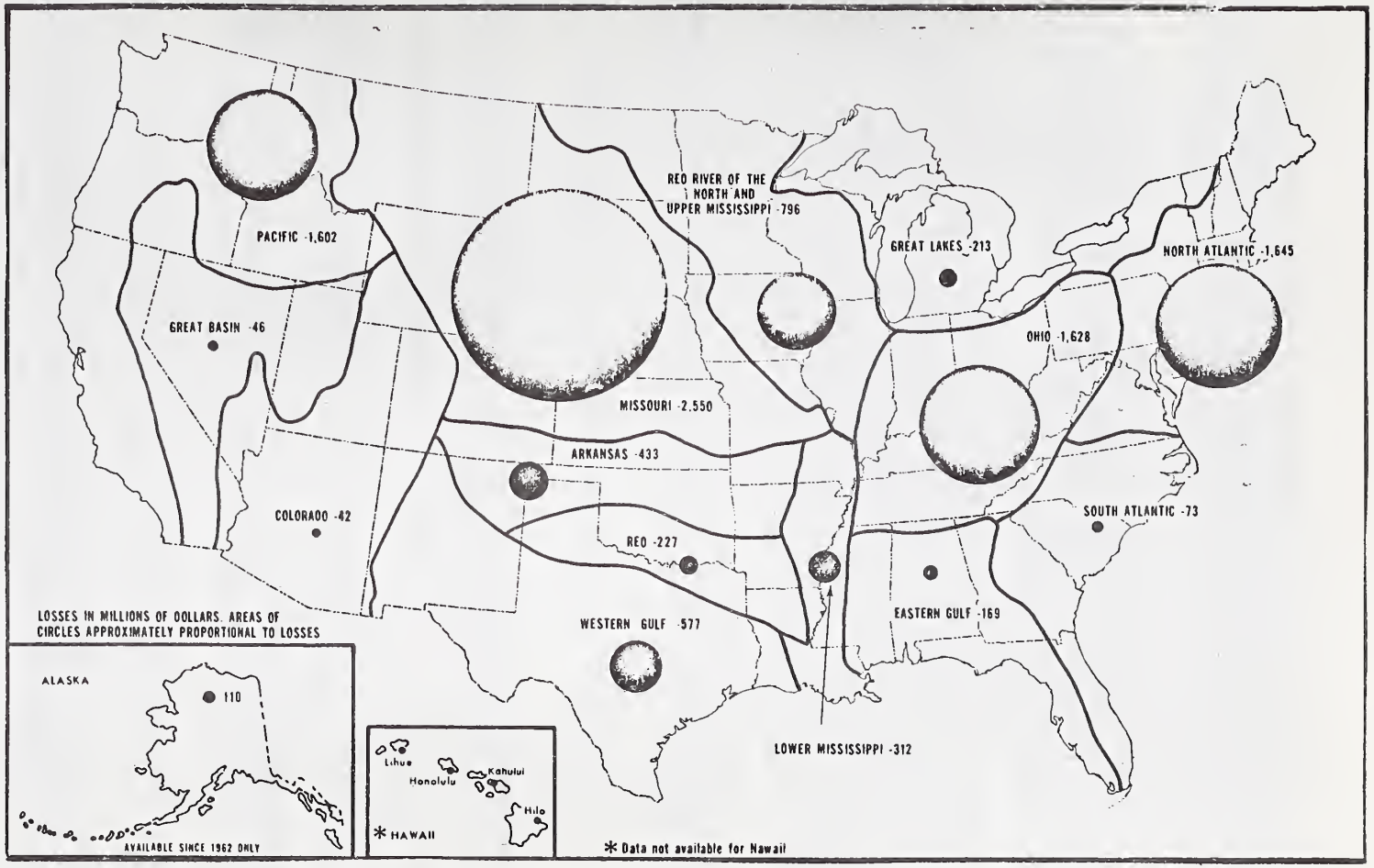

Figure 2.3 Flood losses in the United States by major river systems, 1925-1971 (Millions of Dollars)

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data, National Summary, 1972 (Asheville, N. C.), p. 111.

Total dollar losses for the period 1955-1971 were approximately $5.9 billion.[1] Table 2.7 apportions these losses to each state by year for the seventeen year period. Twice during this period the annual losses exceeded $900 million; i.e., in 1955 losses totaled $995.5 million and in 1969 losses totaled $900.7 million. Figure 2.4 indicates the number of occurrences of floods and flash floods associated with each state's total dollar flood losses for 1955-1971.

In a 1957 cost-benefit analysis produced as a staff report by the Committee on Public Works, it was hypothesized that the "potential average annual flood loss was $911 million."[2] In more recent years the estimated annual losses have been $1.5 to $2.0 billion.[3] By the year 2020, annual flood losses are expected to be $5 billion (disregarding any "major" improvements in the current state of flood protection).[4]

The total number of lives lost and the amount of property damages resulting from floods are shown in Table 2.8 for five-year intervals, 1925-1969. For the period 1925-1971, the average monthly loss is shown in Table 2.9. The month of June has, on the average, produced the most severe losses (13 deaths and $34.8 million in property damages). Average annual loss of lives for the forty-seven year period was 83. Property damages averaged $223.4 million annually. By comparing the average annual property damages (Table 2.9) to each year's damages (Table 2.7) it is seen that during the five year interval 1967-1971 the yearly damages exceeded the average annual damage for each year except 1970. The yearly loss for 1969 ($900.6 million) rose to four times the annual average loss ($223.4 million).

Losses due to floods are probably directly correlated to the population size of flood prone areas. The Natural Disaster Warning Survey Group has estimated that 10 million people occupy recognized flood plain areas and an additional 25 million are subject to the effects of nearby flooding.[5]

Flash flooding is thought to affect 2,500 communities in the United States.[6]

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[1] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data, National Summary, 1972, Vol. 23, p. 114.

[2] Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (The Free Press: New York, 1969), p. 14.

[3] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 1 (Washington, D.C.: Government Printing Office, January 1972), p. 15.

[4] National Waterways Conference, Inc., letter to Chief, OEP PL 91-606 Disaster Study Group, May 26, 1971; cited in Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 1 (Washington, D.C.: Government Printing Office, January 1972); p. 15.

[5] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office, January 1972), p. 8.

[6] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Hydrology, A Plan for Improving the National River and Flood Forecast and Warning Service (Silver Spring, Md., 1969), p. 44.

TABLE 2.7

DOLLAR LOSSES RESULTING FROM FLOODS, BY STATE AND YEAR, 1955-1971
($1,000)

State	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Alabama	3,379	720	2,324	672	-	970	12,625	3,529	1,290	5,343	723	2,366	1,695	409	88	10,991	2,170
Alaska	-	*	-	-	-	-	**	***	-	-	-	-	96,550	-	-	-	9,631
Arizona	226	-	-	-	100	-	325	1,000	-	55	11,330	3,050	3,576	199	-	5,000	3,476
Arkansas	61	255	27,939	6,202	3,090	590	3,503	91	2,500	509	143	5,055	1,497	21,099	3,411	639	2,549
California	165,767	6,745	13	33,093	4	510	95	2,790	11,934	229,109	11,321	24,347	1,370	-	423,206	47,799	3,522
Colorado	2,567	5,135	2,901	240	-	-	-	90	50	-	452,293	707	-	-	66	2,040	-
Connecticut	379,360	-	-	-	-	750	-	-	-	-	-	-	-	100	528	-	-
Delaware	117	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50
District of Columbia	-	51	-	60	-	-	-	-	-	-	-	-	-	-	-	-	-
Florida	105	1,691	-	-	150	12,047	317	1,481	-	426	144	549	95	49	2,959	145	479
Georgia	1	212	1,069	323	-	392	5,236	-	445	3,841	397	1,029	23	133	79	348	243
Hawaii	-	-	-	400	-	-	-	-	2,300	-	-	-	1,029	2,500	-	-	500
Idaho	1,371	6,222	20,996	3	500	-	939	6,112	2,799	11,704	4,164	-	792	-	111	39	1,167
Illinois	102	1,026	1,206	17,970	1,506	7,503	11,553	991	513	3,044	30,564	577	2,629	2,576	9,095	9,124	492
Indiana	1,003	4,021	66,746	52,302	12,959	2,949	13,306	970	9,269	12,327	20	3,098	4,619	22,403	6,672	2,300	1,690
Iowa	35	51	1,543	7,508	129	7,612	9,399	6,779	70	240	32,462	904	4,419	1,650	6,233	977	694
Kansas	474	33	9,164	4,900	4,001	1,947	13,397	1,929	199	370	29,792	97	15,093	2,304	10,991	4,139	1,944
Kentucky	6,629	569	55,233	3,817	2,490	3	12,969	16,995	36,917	35,470	1,044	1,671	17,583	6,030	6,075	707	9,099
Louisiana	30	-	4,147	2,942	-	112	6,074	1,909	-	30	-	250	-	2,910	251	1,000	-
Maine	-	-	-	-	61	-	600	-	-	-	-	529	-	-	300	-	-
Maryland	5,450	937	-	40	-	-	-	-	-	-	53	-	125	-	200	15	8,600
Massachusetts	155,992	-	-	-	-	6,400	-	-	-	-	-	-	-	35,000	-	-	-
Michigan	-	1,279	-	-	-	1,191	-	-	-	-	-	-	-	100	13	-	-
Minnesota	-	11	9,128	17	50	212	552	1,290	29	-	97,603	4,300	-	1,197	67,169	4,350	15
Mississippi	3,132	1,270	2,693	13,929	260	744	15,916	1,982	19	3,152	1,931	2,706	1,192	6,209	1,900	3,586	12,431
Missouri	666	167	9,619	36,719	9,019	13,506	27,375	557	152	6,501	33,976	2,781	39,080	800	39,601	14,926	191
Montana	93	317	33	1	92	57	-	147	149	54,399	253	-	2,947	-	389	561	412
Nebraska	1,500	965	5,963	3,004	3,753	9,984	974	2,630	13,394	5,149	1,369	11,629	40,644	6,029	1,826	-	5,941
Nevada	7,398	237	-	-	-	-	991	792	2,959	2,454	4	307	45	1	-	139	-
New Hampshire	-	-	-	-	4,500	100	-	-	-	-	-	-	-	600	400	-	-
New Jersey	23,102	-	-	3	-	-	-	-	-	-	-	-	1,438	169,990	580	-	136,700
New Mexico	1,066	-	-	-	-	-	-	-	920	1,235	4,933	1,049	-	-	-	-	-
New York	30,072	1,099	166	42	5,667	7,229	909	-	33,102	3,275	-	-	777	-	3,383	3,953	1,000
North Carolina	625	931	768	3,201	506	100	1,400	-	-	15,916	98	199	1,169	-	1,338	2,328	965
North Dakota	2	-	100	-	29	136	-	-	-	-	5,192	9,700	-	-	37,436	13,932	1,266
Ohio	753	1,059	7	4,997	54,840	191	1,217	6,512	22,359	26,039	-	1,993	6,622	20,074	67,919	2,478	792
Oklahoma	977	-	35,665	169	8,907	2,939	2,483	792	413	798	2,508	12	3	3,021	762	5,212	23,166
Oregon	9,515	6,376	310	363	20	360	757	1,550	299	197,101	5,679	2,293	1,044	539	939	2,519	4,360
Pennsylvania	141,381	7,199	1,048	3,592	21,109	3,072	912	15	5,397	10,038	-	705	7,251	421	3,310	365	20,999
Rhode Island	29,930	-	-	-	-	-	-	-	-	-	-	-	588	9,000	-	-	-
South Carolina	74	-	60	690	122	72	369	97	69	1,900	209	140	579	-	625	52	295
South Dakota	11	10	3,069	-	-	3,417	1	3,030	-	-	740	470	1,125	123	31,999	19	-
Tennessee	977	279	5,119	129	-	226	2,263	951	6,292	156	2,472	1,608	1,090	648	1,090	13,260	66
Texas	5,165	3,715	78,891	16,101	2,996	6,093	2,946	1,946	20	5,435	39,305	29,001	99,259	24,297	12,878	3,150	20,536
Utah	229	210	199	10	4	-	261	1,272	64	70	1,740	1,577	453	1,200	237	222	1,033
Vermont	-	-	3	-	-	-	-	-	-	692	-	-	-	100	680	-	-
Virginia	10,695	-	139	-	29	211	231	-	5,937	-	2	-	591	-	123,552	148	1,159
Washington	1,165	6,472	1,694	50	4,914	-	130	-	1,013	11,917	1,012	592	1,910	611	2,722	380	3,909
West Virginia	5,167	3,195	11,052	1,170	709	370	3,455	5,914	17,624	4,169	49	1,668	14,235	47	5,999	297	1,653
Wisconsin	50	335	-	-	1,791	999	1,442	57	142	-	14,067	301	-	-	4,793	-	-
Wyoming	200	11	520	3	-	-	-	-	999	138	390	-	1,006	-	-	500	503
TOTAL	995,491	64,689	390,303	219,255	141,255	92,970	154,033	75,237	177,946	661,842	789,046	117,004	375,219	339,399	900,854	157,453	287,275

*Major Flood in May 1950
**Major Flood in June 1961
***Ice Jam Flooding May 1962
****Serious Flooding June 1962

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data, National Summary, 1972 (Asheville, N. C.), p. 114.

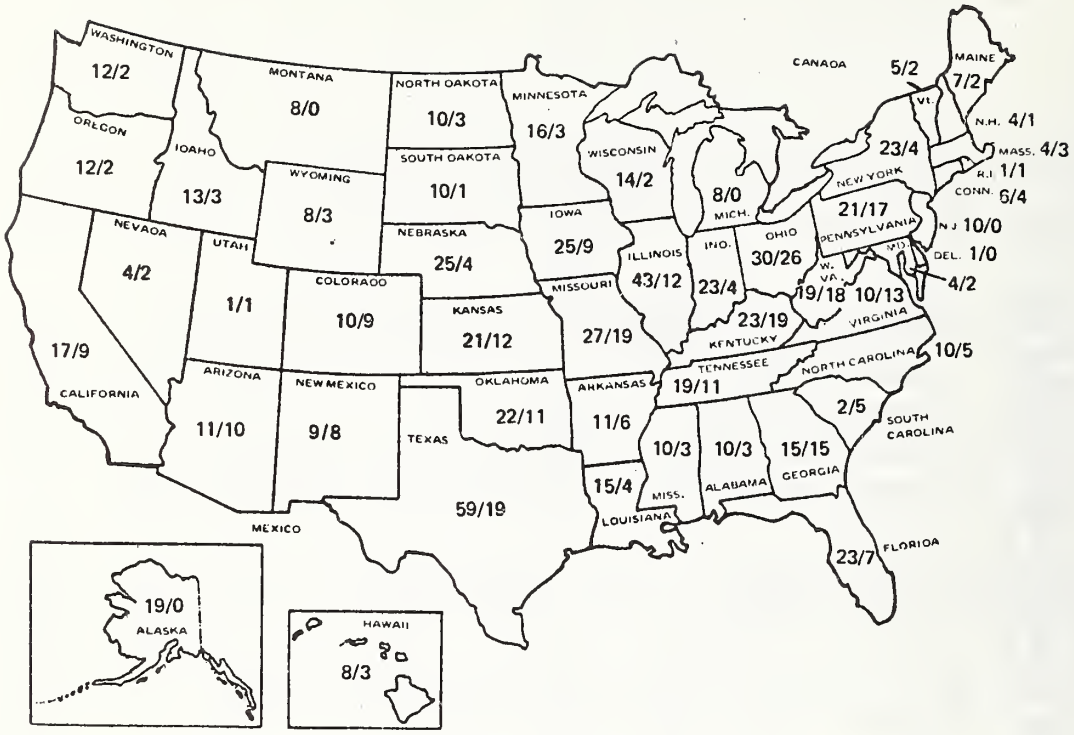

Figure 2.4 Number of floods resulting in assistance from the American Red Cross, 1955-1971

(Numbers with slash show "Floods/Flash Floods")

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office, January 1972), p. 7.

TABLE 2.8

NUMBER OF LIVES LOST AND AMOUNT OF PROPERTY DAMAGES IN THE UNITED STATES DUE TO FLOODS FOR FIVE-YEAR PERIODS, 1925-1969

Years	Property Damages ($1,000,000's)	Number of Lives Lost
1925-1929	495	579
1930-1934	76	146
1935-1939	966	783
1940-1944	481	315
1945-1949	133	304
1950-1954	1680	293
1955-1959	1695	498
1960-1964	1151	242
1965-1969	2520	239

Source: Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 6, 1925-1964; Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office, January 1972), p. 9; and American Red Cross, Highlights of Disaster Relief Services, Fiscal Year 1964-1965, 1965-1966 and Annual Summary of Disaster Services Activities, 1966-1967, 1967-1968, 1968-1969.

TABLE 2.9

AVERAGE NUMBER OF LIVES LOST AND AMOUNT OF PROPERTY DAMAGES IN THE UNITED STATES DUE TO FLOODS, BY MONTH FOR THE PERIOD 1925-1971

Month	Average	
	Number of Lives Lost	Property Damages ($1,000)
January	6	22,532
February	3	6,723
March	7	15,311
April	11	31,929
May	9	22,621
June	13	34,858
July	9	29,228
August	11	25,017
September	4	7,527
October	3	5,655
November	2	1,957
December	5	20,045
Annual Average	83	223,403

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data, National Summary, 1972 (Asheville, N. C.), p. 110.

The losses generated by this type of flooding can be devastating. For example, rains accompanying Hurricane Camille (1969) created flash floods in Virginia which resulted in the deaths of 150 persons and in property damages of $112 million.[1]

A historical account of the more severe river floods occurring in the United States is given by Table 2.10. The greatest property losses to date (1969) were produced by the Kansas-Missouri flood of 1951. Damages amounted to $923.2 million.

A detailed account of the resultant losses from a more recent flood (Agnes, 1972) is given in Table 2.11. Damages to public and private property amounted to nearly $1.5 billion. Combined with $601.2 million of damages to business and industry[2] (not shown in Table 2.11), Agnes floods produced a total $2.1 billion in damages. These damages are 120% greater than the Kansas-Missouri floods of 1951.

It also happens that the communities surrounding a disaster area are affected in several ways. For example, the Black Hills flood (1972) affected tourism and tax revenues of nearby communities that were virtually untouched by the flood itself. Flooding did not occur in the town of Wall, South Dakota, but Wall did experience a decline in tourism[3] and a decrease of $50,000 in sales tax revenues for the third quarter of 1972. For a four county[4] area, a loss of $455,000 in tax revenues was reported. Further estimates indicate a total decrease of $2 billion in sales tax revenues during the second and third quarters for the four counties.[5]

An account of the non-pecuniary losses resulting from floods and flash floods are given in Table 2.12 for fiscal years 1960-1973. The effects of the Agnes floods can be seen in the data for fiscal year 1972. A total of 519 persons were killed in that year; more than 156,000 families suffered losses; 7,346 dwellings were destroyed and 133,803 were damaged. A record number of persons were also injured or ill (16,587) and were given emergency mass care (604,071) that year.

2.3 Earthquakes

It has been said that earthquakes present the "greatest potential for catastrophic--even cataclysmic--losses in concentrated urban areas."[6] Losses are caused by the earth's movements but additional losses result from earthquake produced fires, floods, landslides

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[1] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 1 (Washington, D.C.: Government Printing Office, January 1972), p. 25.

[2] Executive Office of the President, Office of Emergency Preparedness, The Federal Response to Tropical Storm Agnes (Washington, D.C.: Government Printing Office, May 1973), pp. 6-8.

[3] U.S. Congress, Senate, Committee on Public Works, To Investigate the Adequacy and Effectiveness of Federal Disaster Relief Legislation, Part 2, Hearings, before the 93rd Cong., 1st sess., March 30 and 31, 1973, p. 340.

[4] Ibid., p. 341.

[5] Ibid.,

[6] U.S. Department of Housing and Urban Development, Federal Insurance Administration, Report on Earthquake Insurance to the Congress of the United States. Pursuant to Section Five of the Southeast Hurricane Disaster Relief Act of 1965 (Washington, D.C. 1971), p. 8.

TABLE 2.10

SEVERE RIVER FLOOD DISASTERS IN THE UNITED STATES, 1935-1969

Year	Month	Location	Number of Lives Lost	Property Damages ($1,000,000)
1935	May-July	Republican and Kansas Rivers	110	18.0
	July	Upper Susquehanna	52	26.0
1936	March-April	Eastern United States	107	270.0
1937	Jan.-Feb.	Ohio and Lower Mississippi River Basins	137	417.7
1938	March	Southern California	79	24.5
1939	July	Licking and Kentucky Rivers	78	1.7
1940	August	Southern Virginia and Carolinas, and Eastern Tennessee	40	12.0
1943	April-June	Maumee, Wabash, Upper Mississippi, Missouri, White, and Arkansas River Basins	60	172.0
1947	May-July	Lower Missouri and Middle Mississippi River Basins	29	235.0
1948	May-June	Columbia Basin	35	101.7
1950	June	Central West Virginia	31	4.0
1951	June-July	Kansas-Missouri	28	923.2
1955	August	Hurricane floods in Northeast	187	714.1
	December	West Coast	61	154.5
1963	March	Ohio River Basin	26	97.6
1964	June	Montana	31	54.3
	December	California and Oregon	40	415.8
1965	June	Sanderson, Texas, flash flood	26	2.7
1969	Jan.-Feb.	California	60	399.2
	July	Northern Ohio	30	87.9
	August	James River Basin in Virginia	154	116.0

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C., Government Printing Office, January 1972), p. 8.

Table 2.11

CASUALITIES, PHYSICAL DAMAGE, AND ESTIMATED PECUNIARY LOSSES DUE TO AGNES FLOODS

State	(1) Lives Lost	(2) Hospitalized for Injury or Illness	(3) Damage to Public Property ($1,000's)	(4) Damage to Private Property ($1,000's)	(5) Dwellings[a]	
					Destroyed	Damaged[b]
Florida	8	36	3,000	8,000	273	821
Georgia	0	1	d	d	d	8[c]
Maryland	20	6	8,176	54,146	153	909
New York	31	118	192,385	539,592	763	5,289
Pennsylvania	48	799	184,049	788,869	3,587	35,320
Virginia	13	9	12,786	53,780	220	1,757
West Virginia	0	1	1,876	10,835	199	435
TOTALS	122[e]	970[e]	404,031[f]	1,053,153[f]	5,222[g]	44,662[g]

[a] Includes mobile homes.

[b] Major damage only.

[c] Includes Georgia and North Carolina.

[d] Not reported in sources.

[e] Includes Washington, D.C.

[f] Includes Ohio.

[g] Includes Washington, D.C. and Ohio.

Source: U.S. Congress, Senate, Committee on Public Works, To Investigate the Adequacy and Effectiveness of Federal Disaster Relief Legislation, Part 3, Hearings, before the 93rd Cong., 1st sess., May 11 and 12, 1973, pp. 1502, 1503, 1505, Columns (1), (2), and (5) taken from American National Red Cross, September 27, 1972; Columns (3) and (4) taken from OEP Analysis of Statistics, Sept. 29 and Nov. 13, 1972.

TABLE 2.12

SELECTED DATA FOR FLOODS AND FLASH FLOODS
(Involving More than Five Families)

Fiscal Year	Persons Killed	Persons With Injuries or Illnesses	Persons Given Emergency Mass Care	Families Suffering Loss	Dwellings	
					Destroyed	Damaged
1960	17	521	42,876	a	57	18,318
1961	132	2,070	50,829	a	111	15,070
1962	55	1,901	55,968	a	361	19,233
1963	39	396	37,838	a	222	26,931
1964	34	1,782	43,785	a	390	29,387
1965	139	4,579	247,556	55,758	2,207	36,529
1966	22	102	63,527	10,809	91	9,131
1967	16	161	43,632	26,654	108	22,353
1968	38	824	49,059	21,901	84	14,224
1969	24	284	160,417	20,653	71	17,674
1970	51	783	66,252	41,182	83	33,769
1971	22	58	50,675	25,018	105[b]	6,993[b]
1972	519	16,587	604,071	156,541	7,346[b]	133,803[b]
1973	105	1,559	148,575	99,245	3,229[b]	81,467[b]

[a]Not reported.

[b]Including mobile homes.

Source: American National Red Cross, Highlights of Disaster Relief Services, Fiscal Year 1959-60, 1960-61, 1961-62, 1962-63, 1964-65; and Annual Summary of Disaster Services Activities, 1966-67, 1967-68, 1968-69, 1969-70, 1971-72, 1972-73.

and tsunamis.[1] Since 1865, major earthquakes in the United States have produced $1.86 billion in property damages (Table 2.13). Since 1811, earthquakes have accounted for more than 1,660 deaths.[2] The San Francisco earthquake of 1906 caused $524 million dollars in property damages ($500 million attributed to fire loss). Estimated damages resulting from the Alaska earthquake of 1964 amounted to $500 million. In the 1971 San Fernando earthquake, damages totaled $553 million.

Without some form of protection, damages are likely to be even greater in the future than in the past if earthquakes continue to occur with the same frequency and intensity, because positive population growth rates and economic development increase potential losses. For example, the damages to dwellings resulting from another earthquake in San Francisco of the same intensity as the one in 1906 have been estimated at $25 billion.[3]

The intensities of earthquakes and the damages produced provide a basis for the construction of a seismic risk map as shown in Figure 2.5. Risk zones may vary from 0, no damage, to 3, major damage. The figure shows that parts of Washington, Utah, Idaho, Montana, South Carolina, the Northeast, the South Central states, and a major portion of California are subject to high seismic risk.

The location and intensity of earthquakes occurring in the United States through 1966 is shown in Figure 2.6. A small dot (•) indicates where the intensity was strong enough to affect more than 25,000 square miles; a large dot (●) indicates where the intensity was strong enough to affect more than 150,000 square miles or to cause damages ranging from several thousand to $100,000; a small encircled dot, ◎ , indicates where intensity was strong enough to affect more than 500,000 square miles or to cause damages of $100,000 to $1,000,000; and a large encircled dot, ◉ , indicates where the intensity was strong enough to affect more than 1 million square miles or to cause damages greater than $1,000,000.[4] Although California has experienced the majority of earthquakes, the figure shows that earthquakes have occurred throughout the United States.

The record of lives lost and property damages due to earthquakes for five-year intervals is shown in Table 2.14. Over the 41 year period from 1925-1965, a total of 318 lives were lost and property was damaged in the amount of $592 million. During the 1960-1964 period 68% ($405 million) of the total property damages occurred and 36% (115) of the total number of lives were lost. Another source reports that the Alaska earthquake of 1964 alone caused $500 million in property damages and 131 deaths.[5]

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[1] Tsunamis are ocean waves produced by earthquakes, volcanic eruption, or submarine disturbances.

[2] U.S. Department of Housing and Urban Development, Federal Insurance Administration, Report on Earthquake Insurance to the Congress of the United States, Pursuant to Section Five of the Southeast Hurricane Disaster Relief Act of 1965 (Washington, D.C. 1971), p. 8.

[3] Ibid.

[4] U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, A Preliminary Study of Engineering Seismology Benefits, by Joseph D. Crumlish and George F. Wirth (Washington, D.C.: Government Printing Office, August 1967), p. 7.

[5] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 1 (Washington, D.C.: Government Printing Office, January 1972), p. 73.

TABLE 2.13

PROPERTY DAMAGES RESULTING FROM MAJOR U.S. EARTHQUAKES, 1865-1971
($1,000,000)

1865	San Francisco, Calif.	.5
1868	San Francisco, Calif.	.4
1872	Owens Valley, Calif.	.3
1886	Charleston, S.C.	23.0
1892	Vacaville, Calif.	.2
1898	Mare Island, Calif.	1.4
1906	San Francisco, Calif.	24.0
	Fire loss	500.0
1915	Imperial Valley, Calif.	.9
1918	Puerto Rico (tsunami damage from earthquake in Mona Passage)	4.0
1918	San Jacinto and Hemet, Calif.	.2
1925	Santa Barbara, Calif.	8.0
1933	Long Beach, Calif.	40.0
1935	Helena, Mont.	4.0
1940	Imperial Valley, Calif.	6.0
1941	Santa Barbara, Calif.	.1
1941	Torrance-Gardena, Calif.	1.0
1944	Cornwall, Canada-Massena, N.Y.	2.0
1946	Hawaii (tsunami damage from earthquake in Aleutians)	25.0
1949	Puget Sound, Wash.	25.0
1949	Terminal Island, Calif. (oil wells only)	9.0
1951	Terminal Island, Calif. (oil wells only)	3.0
1952	Kern County, Calif.	60.0
1954	Eureka-Arcata, Calif.	2.1
1954	Wilkes-Barre, Pa.	1.0
1955	Terminal Island, Calif. (oil wells only)	3.0
1955	Oakland-Walnut Creek, Calif.	1.0
1957	Hawaii (tsunami damage from earthquake in Aleutians)	3.0
1957	San Francisco, Calif.	1.0
1959	Hebgen Lake, Mont. (damage to timber and roads)	11.0
1960	Hawaii and U.S. West Coast (tsunami damage from earthquake off Chile coast)	25.5
1961	Terminal Island, Calif. (oil wells only)	4.5
1964	Alaska and U.S. West Coast (includes tsunami damage from earthquake near Anchorage)	500.0
1965	Puget Sound, Wash.	12.5
1966	Dulce, N. Mex.	.2
1969	Santa Rosa, Calif.	6.3
1971	San Fernando, Calif.	553.0
	Total	1862.1

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D.C.: Government Printing Office, January 1972), p. 82.

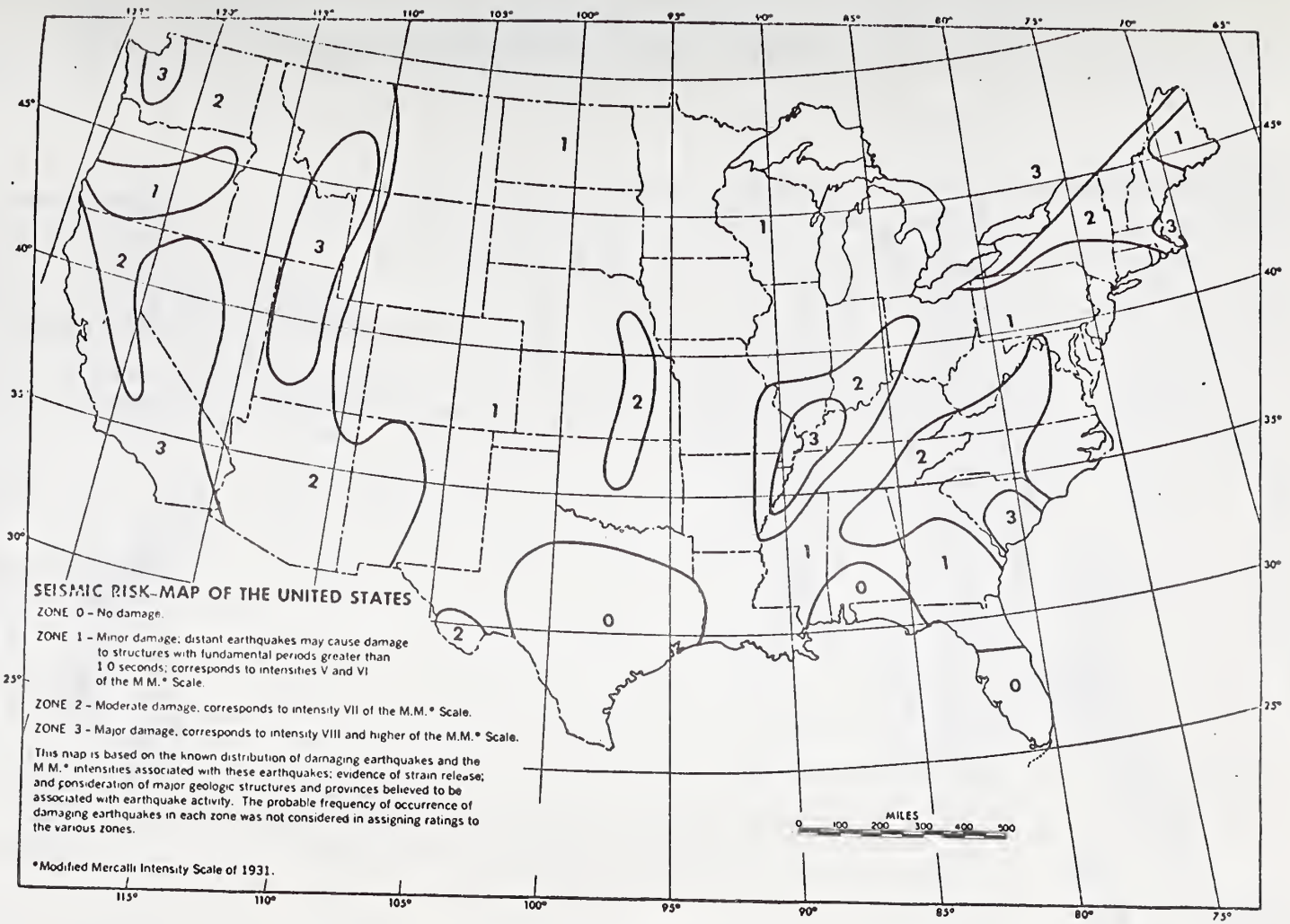
SEISMIC RISK-MAP OF THE UNITED STATES
ZONE 0 - No damage.
ZONE 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds; corresponds to intensities V and VI of the M.M.* Scale.
ZONE 2 - Moderate damage, corresponds to intensity VII of the M.M.* Scale.
ZONE 3 - Major damage, corresponds to intensity VIII and higher of the M.M.* Scale.
This map is based on the known distribution of damaging earthquakes and the M.M.* intensities associated with these earthquakes; evidence of strain release; and consideration of major geologic structures and provinces believed to be associated with earthquake activity. The probable frequency of occurrence of damaging earthquakes in each zone was not considered in assigning ratings to the various zones.
*Modified Mercalli Intensity Scale of 1931.
MILES
0 100 200 300 400 500

Figure 2.5 Seismic risk map of the United States

Source: S. T. Algermissen, "Seismic Risk Studies in the United States, "Proceedings of the Fourth World Conference on Earthquake Engineering (Chilean Association Seismic and Earthquake Engineering, Santiago, Chile, 1969); reproduced in Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness (Washington, D.C.: Government Printing Office, January 1972), p. 75.

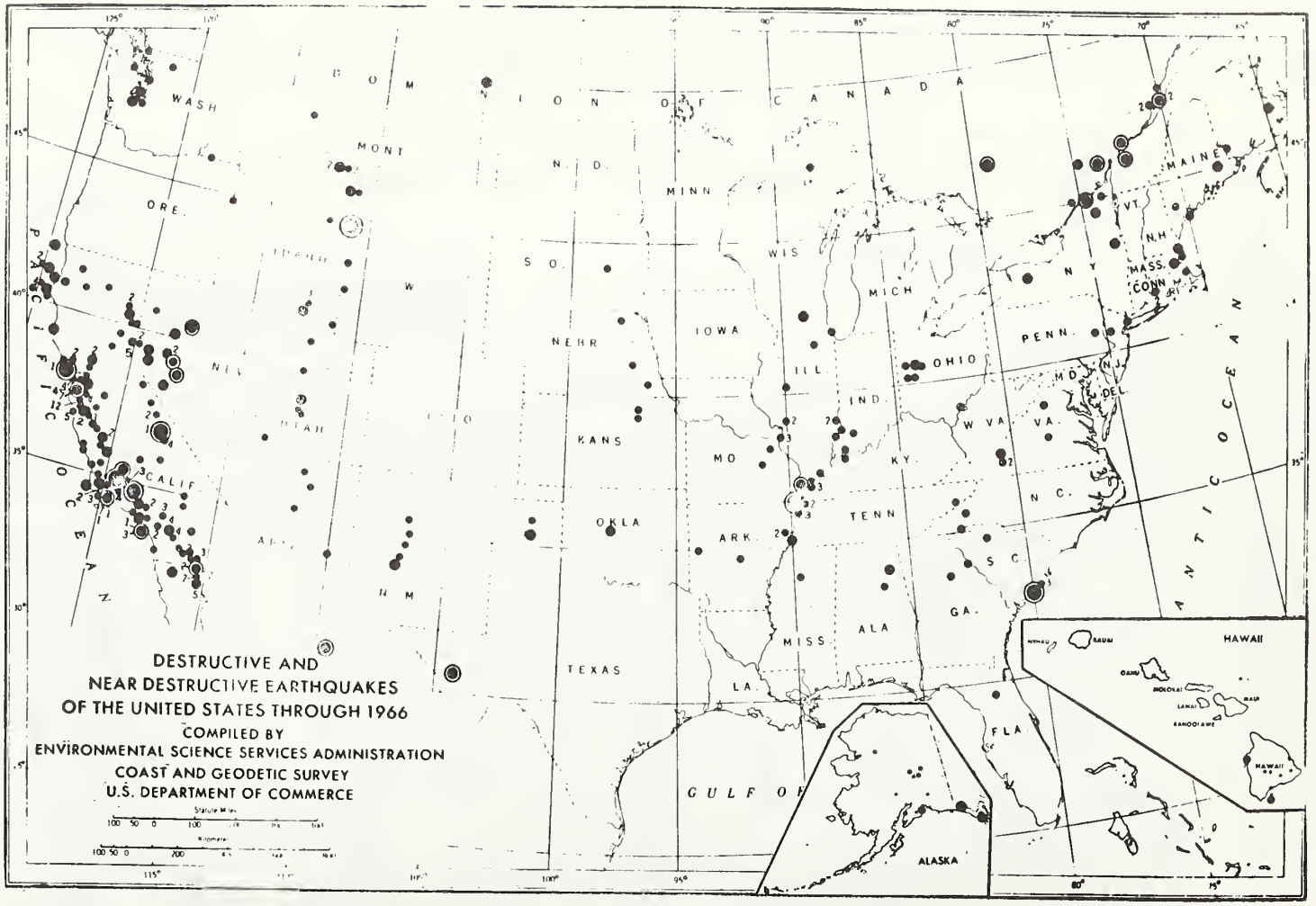

Figure 2.6 Destructive Earthquakes in the United States Through 1966

Source: U.S. Department of Commerce, Environmental Science Services Administration, Coast & Geodetic Survey, A Preliminary Study of Engineering Seismology Benefits (Washington, D. C.: Government Printing Office, August 1967), p. 8.

TABLE 2.14

LIVES LOST AND VALUE OF PROPERTY DAMAGES IN THE UNITED STATES DUE TO EARTHQUAKES FROM 1925-1964 BY FIVE-YEAR PERIODS, AND FOR 1965

Years	Value of Property Damages (In Millions of Dollars)	Lives Lost
1925-1929	8	13
1930-1934	40	117
1935-1939	4	4
1940-1944	7	9
1945-1949	34	8
1950-1954	65	15
1955-1959	16	34
1960-1964	405	115
1965	13	3
TOTAL	592	318

Source: Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 6.

Table 2.15 lists the casualities, families affected, and physical damages to dwellings and small businesses as a result of five severe earthquakes that occurred between 1959 and 1971. The San Fernando earthquake caused only about half the number of deaths as the Alaska earthquake, but more than 21 times the destruction and damage to dwellings. It should be noted, however, that the San Fernando earthquake recorded a magnitude of 6.6 on the Richter scale, while the Alaska earthquake recorded a magnitude of approximately 8.5.[1] Thus, the magnitude of an earthquake, as measured on the Richter scale, is not the sole indicator of damage of an earthquake. Total damages, for example, are obviously related to population density.

Tables 2.16 and 2.17 give more detailed information of the losses caused by the Alaska and San Fernando earthquakes. Table 2.16 shows damages of $71.2 million to Federal facilities alone from the Alaska earthquake. The losses due to the San Fernando earthquake, Table 2.17, are broken down into public and private sector losses. Dollar losses were shared about equally for each sector with the private and public sectors incurring 52% ($259 million) and 48% ($238 million), respectively.

2.4 Tornadoes

Tornadoes have caused the loss of more lives than any other natural disaster in the United States.[2] Over a 57 year period, 1916-1972, tornadoes took the lives of 10,500 persons, resulting in an annual average of 184 deaths (Table 2.18). For the last 15 years, however, Table 2.18 shows that the annual death toll has remained below the average (184 deaths) with the exception of 1965. Since 1953, the annual average number of deaths due to tornadoes has decreased 42%.[3] The decrease can be attributed to advancements in a national warning system.[4]

Table 2.18 also shows that for the past 8 years the United States has experienced annual tornado property losses of $50 million and more (category 8). For the last 31 years annual losses have exceeded $5 million (category 7). These current dollar losses represent conservative estimates and in effect serve as a lower bound to annual property losses. The usefulness of Table 2.18 may be found more in the frequency of tornadoes reported in various categories. Each of 11 tornadoes in 1965 caused property damages of $5 million and over (category 7 and over). During 1970 there were 6 such tornadoes and in 1971 there were 5.

Tornadoes occur in all 50 states.[5] Figure 2.7 shows the incidence by state for

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[1] Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 1 (Washington, D.C.: Government Printing Office, January 1972), p. 73.

[2] Ibid., p. 35.

[3] Ibid.

[4] Ibid.

[5] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Tornado Preparedness Planning (Washington, D.C.: Government Printing Office, October 1970), p. 24.

TABLE 2.15

DATA FOR FIVE SEVERE EARTHQUAKES IN THE UNITED STATES

Year	Location	Persons Killed	Persons Injured	Families Suffering Loss	Families Assisted by American Red Cross	Dwellings		Small Businesses Destroyed and Major Damage
						Destroyed	Damaged	
1959	Montana	9	110	102	12	a	102	a
1964	Alaska	108	524	7,000	930	515[b]	1,245	117
1965	Northwest (Washington)	5	47	10,577	63	2	10,573	2
1969	California (Santa Rose)	a	a	200	42	28	22	49
1971	Southern California	58	3,500	50,061	10,984	750	37,834	254
	TOTALS	181	4,181	67,940	12,031	1,295	49,776	422

[a]None reported by the American Red Cross.

[b]Includes mobile homes.

Source: American Red Cross, December 12, 1973.

TABLE 2.16

ESTIMATED DAMAGES TO FEDERAL FACILITIES IN ALASKA
RESULTING FROM THE 1964 EARTHQUAKE

Federal Agency	*Primary Loss*	*Estimated Damage ($Million)*
Dept. of Defense	Barracks and other facilities at Fort Richardson, Elmendorf Air Force Base, and Kodiak Naval Station	35.6
Dept. of Interior	Alaska Railroad	31.5
Dept. of Commerce	Damaged facilities	1.8
Federal Aviation Agency	Facilities at Anchorage International Airport	1.3
Dept. of Health, Education, and Welfare	Public Health Service, Native Hospital	.6
General Services Administration	Office supplies and equipment	.4
TOTAL		71.2

Source: Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 126.

TABLE 2.17

LOSSES DUE TO THE SAN FERNANDO EARTHQUAKE
BY PRIVATE AND PUBLIC SECTOR

Sector	Losses	
Private Sector:		
Buildings, excluding land and contents:		
Los Angeles City	$170,300,000	
San Fernando City	35,500,000	
Elsewhere	18,500,000	
Non-building structures, excluding land	35,000,000	
TOTAL		$259,300,000
Public Sector:		
Los Angeles City	103,300,000	
San Fernando City	200,000	
Los Angeles County	100,000,000	
Other local jurisdictions	5,000,000	
Porter Ranch (aftershock damage)	8,000,000	
Utilities	22,000,000	
TOTAL		238,500,000
GRAND TOTAL		$497,800,000

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, A Study of Earthquake Losses in the San Francisco Bay Area, A Report Prepared for the Office of Emergency Preparedness, Part B, p. 17.

TABLE 2.18

FREQUENCY OF TORNADOES, RESULTING CASUALITTES, AND PROPERTY LOSSES, 1916-1972

YEAR	Number Tornadoes	Tornado Days	Total Deaths	Most Deaths in Single Tornado	Total Property Losses by Category[a]	FREQUENCY OF TORNADOES BY CATEGORY[a]		
						Category 5	Category 6	Category 7 and Over
1916	90	36	150	30	6	7	1	0
1917	121	38	509	101	7	21	9	0
1918	81	45	135	36	7	20	5	0
1919	64	35	206	59	7	10	2	0
1920	87	50	498	87	7	14	10	0
1921	105	55	202	61	7	22	3	0
1922	108	64	135	16	7	27	5	0
1923	102	59	109	23	6	21	1	0
1924	130	57	376	85	7	26	11	1
1925	119	65	794	689	7	34	2	1
1926	111	57	144	23	6	28	0	0
1927	163	62	540	92	7	42	9	1
1928	203	79	92	14	7	40	7	0
1929	197	74	274	40	7	48	4	0
1930	192	72	179	41	7	38	6	0
1931	94	57	36	6	6	14	1	0
1932	151	67	394	37	7	23	1	1
1933	258	96	362	34	7	46	9	0
1934	147	77	47	6	6	10	3	0
1935	180	77	70	11	6	29	0	0
1936	151	71	552	216	7	17	5	1
1937	147	75	29	5	6	24	0	0
1938	213	76	183	32	7	29	6	0
1939	152	75	87	27	7	21	3	0
1940	124	62	65	18	7	13	2	0
1941	118	57	53	25	6	24	1	0
1942	167	66	384	65	7	42	10	0
1943	152	61	58	5	7	28	8	0
1944	169	68	275	100	7	50	9	0
1945	121	66	210	69	7	21	10	1
1946	106	65	78	15	7	29	7	0
1947	165	78	313	169	7	46	7	1
1948	183	68	140	33	7	62	11	2
1949	249	80	212	58	7	54	13	0
1950	199	88	70	18	7	47	9	0
1951	272	113	34	6	7	35	11	2
1952	236	98	230	57	7	53	19	0
1953	437	136	516	116	8	63	18	7
1954	549	159	35	6	7	63	8	1
1955	593	153	125	80	7	74	13	1
1956	532	155	83	25	7	83	24	1
1957	864	154	191	44	8	129	26	3
1958	565	166	66	19	7	70	8	1
1959	589	156	58	21	7	70	4	1
1960	618	172	47	16	7	65	11	1
1961	682	169	51	16	7	103	21	1
1962	658	152	28	17	7	51	10	0
1963	461	141	31	5	7	77	15	1
1964	713	156	73	22	7	113	17	5
1965	899	181	298	44	8	126	30	11
1966	570	150	99	58	8	79	13	4
1967	912	173	116	33	8	125	33	8
1968	661	171	131	34	8	82	26	6
1969	604	155	66	32	8	98	16	3
1970	649	171	73	26	8	97	24	6
1971	888	192	156	58	8	71	30	5
1972	741	194	27	6	8	100	28	1
Means: 1953-72	659	163	114	---	---	87	19	3

NOTE: -- The above estimated losses are based on values at time of occurrence.

[a]Storm damages in categories:

5. $50,000 to $500,000
6. $500,000 to $5 million
7. $5 million to $50 million
8. $50 million and over.

Source: Executive Office of the President, Office of Emergency Preparedness, Disaster Preparedness, Vol. 3 (Washington, D. C., Government Printing Office, January 1972), p. 30.

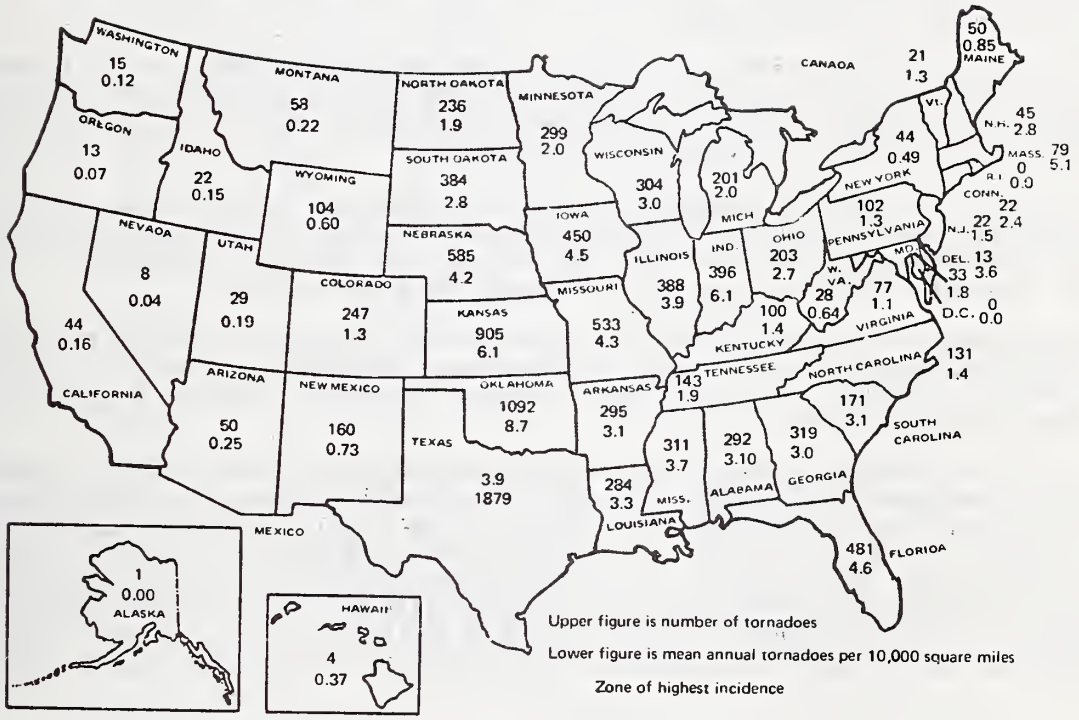

Figure 2.7 Tornado Incidence by State, 1953-1970

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Tornado Preparedness Planning (Washington, D.C.: Government Printing Office, October 1970), p. 26.

1953-1970.[1] Although Texas has experienced the greatest number of tornadoes (1,879), Oklahoma reportedly has a greater number of tornadoes (8.7) per 10,000 square miles than does any other state. In general the southeastern and midwestern states experienced the highest annual average number of tornadoes for the period.

In addition to being widespread, tornadoes occur frequently throughout the year, as shown in Figure 2.8. The peak tornado months are April, May, and June. For the period 1953-1969, 2,465 tornadoes struck in the peak month of May. The number of tornado deaths has been correspondingly high during these months. For April, May, and June the total number of deaths during the same period was 578, 547, and 367, respectively. Figure 2.9 indicates that the states with the highest fatalities (per 10,000 square miles) are Indiana (40), Michigan (37), and Alabama (35).

The annual impact of tornadoes as reported by the American Red Cross is shown in Table 2.19. Since fiscal year 1965 an average of more than 8,300 families per year have suffered losses from tornadoes. Over the 14 year period described in Table 2.19, tornadoes destroyed and damaged an average of 6,871 dwellings per year.

Casualities and losses for individual tornadoes are reported in Table 2.20. The most devastating tornado disaster for the period was from a group of storms called the Palm Sunday Tornadoes, which resulted in 202 deaths and 1,813 destroyed dwellings (more than twice the number destroyed by any other tornado during the period).

The pecuniary losses to properties as a result of some individual tornadoes are listed in Table 2.21. On four occasions since 1965, tornadoes caused property damages of $100 million and more. The damages produced by the Palm Sunday Tornadoes, previously mentioned, amounted to $200 million.

Annual dollar losses resulting from tornadoes have not been reported in such a manner so as to give researchers all the data they need for evaluating tornadoes. Broad categories of dollar losses, such as those shown in Table 2.18, are usually the best statistics available. For example, in 1965 and 1970 Table 2.18 shows losses of $50 million and over (category 8). Yet if we compare these figures with the property damages shown in Table 2.21, we find that in 1965 the Palm Sunday Tornadoes produced $200 million in property damages and that in 1970 the tornadoes in Lubbock, Texas, caused $135 million in property damages. The $50 million and over category now appears very inappropriate for reporting tornado losses.

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[1] These statistics are not necessarily complete, since some tornadoes that occur in unpopulated areas are not recorded.

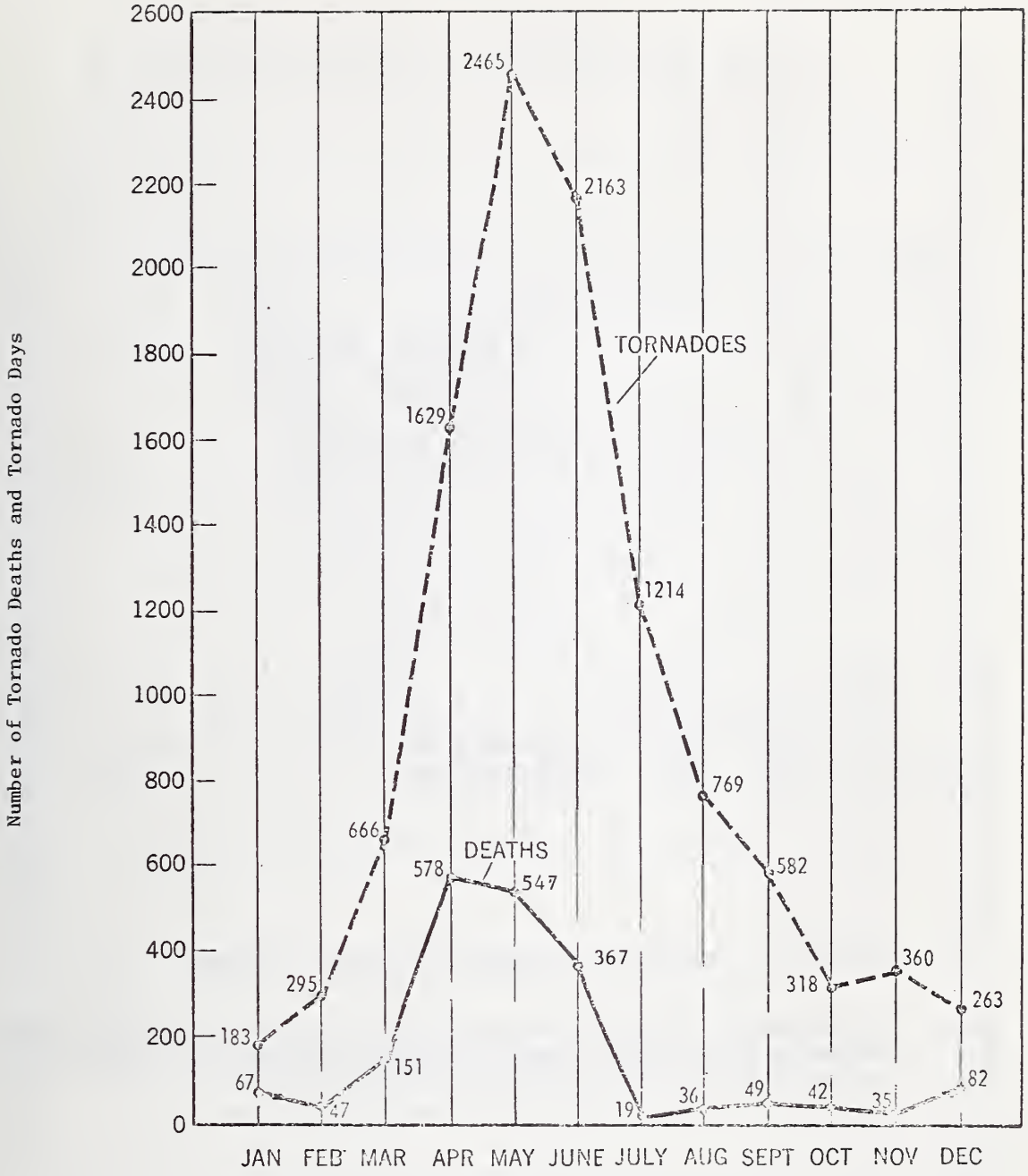

Figure 2.8 Distribution of Tornado Incidence and Resulting Deaths By Months, 1953-1969

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Tornado Preparedness Planning (Washington, D.C.: Government Printing Office, October 1970), p. 28.

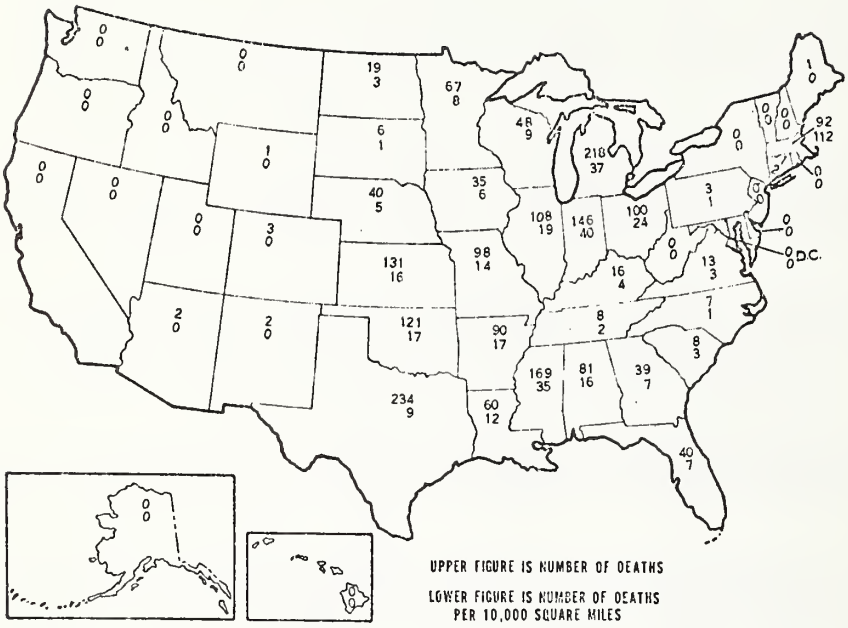

Figure 2.9 Deaths Due to Tornadoes, By State, 1953-1969

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Tornado Preparedness Planning (Washington, D.C.: Government Printing Office, October 1970), p. 26.

TABLE 2.19

SELECTED DATA ON THE IMPACT OF TORNADOES THAT AFFECT MORE THAN FIVE FAMILIES

Fiscal Year	Persons Killed	Persons With Injuries or Illnesses	Persons Given Emergency Mass Care	Families Suffering Loss	Dwellings Destroyed	Dwellings Damaged
1960	53	820	13,675	a	628	7,167
1961	15	440	9,355	a	380	9,657
1962	23	401	12,106	a	349	3,751
1963	29	481	5,176	a	430	3,453
1964	44	711	8,124	a	703	8,753
1965	280	3,743	90,984	12,821	2,802	7,603
1966	92	1,606	2,775	9,604	1,357	6,578
1967	90	1,926	44,443	9,324	995	7,079
1968	139	2,713	53,919	10,082	1,533	6,747
1969	50	768	22,157	5,758	325	4,567
1970	78	2,521	33,969	9,249	841	6,113
1971	145	1,823	34,451	8,543	1,191[b]	5,225[b]
1972	22	653	12,833	3,651	332[b]	2,429[b]
1973	31	993	18,822	5,934	1,135[b]	4,068[b]
TOTAL	1,091	19,599	362,789	74,966	13,001	83,190
AVERAGE[c]	78	1,400	25,914	8,330	929	5,942

[a] Not reported.
[b] Including mobile homes.
[c] Rounded off.

Source: American National Red Cross, Highlights of Disaster Relief Services, Fiscal Year 1959-60, 1961-62, 1962-63, and Annual Summary of Disaster Services Activities, 1966-67, 1967-68, 1968-69, 1969-70, 1970-71, 1971-72, 1972-73.

TABLE 2.20

CASUALTIES AND LOSSES FROM SEVERE TORNADOES, 1955-1971

NAME OF DISASTER OPERATION	DATE OCCURRED	PERSONS			DWELLINGS		TOTAL NO. FAMILIES SUFFERING LOSS
		KILLED	INJURED OR ILL	HOSPITAL.	DESTROYED	DAMAGED	
OKLA.KANSAS TORNADOES	5/25/55	101	572	225	433	584	1199
OKLA.,KANSAS, MO. TORNADOES	4/25/56	7	208	62	147	477	694
MISSOURI - KANSAS TORNADOES	5/20/57	54	448	163	625	1256	2261
MISSISSIPPI - ALABAMA TORNADOES	2/26/58	15	123	62	143	276	494
WEST CENTRAL WISCONSIN TORNADOES	6/4/58	27	239	117	177	317	557
Palm Sunday Tornadoes - INDIANA, OHIO - MAJOR - KENTUCKY, W.VA. - MINOR	4/11/65	202	2047	636	1813	2876	5492
EASTERN KANSAS TORNADOES	6/8/66	17	457	103	885	3317	5096
LUBBOCK, TEXAS TORNADO	5/11/70	26	1672	107	549	2033	3300
WEST CENTRAL MISSISSIPPI TORNADOES	2/21/71	117	1083	434	658	1014	2487

Source: Data from American Red Cross.

TABLE 2.21

PROPERTY DAMAGES RESULTING FROM INDIVIDUAL TORNADOES

Year	Disaster	Property Damages ($1,000,000)
1965	Palm Sunday Tornadoes	200
1966	Topeka, Kansas	100
1967	St. Louis County, Missouri	15
1968	Charles City, Iowa	30
1969	Salina, Kansas	10
1970	Lubbock, Texas	135
1971	Mississippi Delta Tornadoes	20
1972	Vancouver, Washington	5-6
1973	North Central, Georgia	113

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, General Summary of Tornadoes 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972 (Washington, D.C.: Government Printing Office); and Storm Data and Unusual Weather Phenomena, March 1973.

3. BENEFIT-COST ANALYSIS

The previous chapter discussed the past dollar losses and other consequences of natural disasters. The reasons for studying these past losses is to determine the potential benefits that might be realized from protection against future disasters. Society can purchase protection through various techniques that are effective in reducing future losses. The problem facing society is one of deciding how much disaster protection it is economical to buy. The present chapter will apply a well-known method, called benefit-cost analysis, for choosing society's optimal level of protection against natural disasters.

Benefit-cost analysis can also be applied to determining the proper channeling of research money into disaster mitigation programs. This is accomplished by examining the potential benefits and costs of alternative research strategies. It is desirable to determine if the potential benefits from various research programs will justify their costs. When several research possibilities exist, a benefit-cost analysis provides a rational approach for choosing among research projects.

The first section of this chapter discusses the principles of benefit-cost analysis and their application to evaluating alternative levels of protection against natural disasters. The second section will examine the results of two studies in disaster mitigation.

3.1 Benefit-Cost Models for Disaster Mitigation

Alternative levels of protection against natural disasters provide certain benefits and costs for society. Social benefits are the reduction of future potential losses resulting from natural disasters. The costs (opportunity costs) society must incur to achieve these benefits are the benefits foregone by taking resources out of their alternative uses and applying them to disaster protection. To use resources efficiently, society must choose the optimal level of protection that maximizes the difference between the present value of total benefits and total costs.[1] A benefit-cost model can be used to determine society's optimal level of protection against natural disasters.

The essential features of a benefit-cost model can be illustrated by graphical analysis. In Figure 3.1 the horizontal axis measures alternative levels of protection, P. The vertical axis measures the dollar value of total benefits and total costs for corresponding levels of protection. The total benefits curve is shown increasing at a decreasing rate. This is a tenable proposition as long as equal increments of protection result in successively smaller reductions in losses.

The total costs of protection in Figure 3.1 are depicted as increasing at an increasing rate. This reflects diseconomies of scale that result when equal increments in productive resources yield diminishing increments in disaster protection.

The decision rule for optimization in benefit-cost analysis is to choose that program or level of protection which maximizes the difference between total benefits and total costs;

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[1] Because of a positive rate of time preference, the potential benefits and costs do not have the same value in the future as they do today. Based on society's valuation of future relative prices, a future stream of benefits and costs can be discounted to their present value. Throughout the following benefit-cost analysis all dollar values of benefits and costs will be taken to be present values.

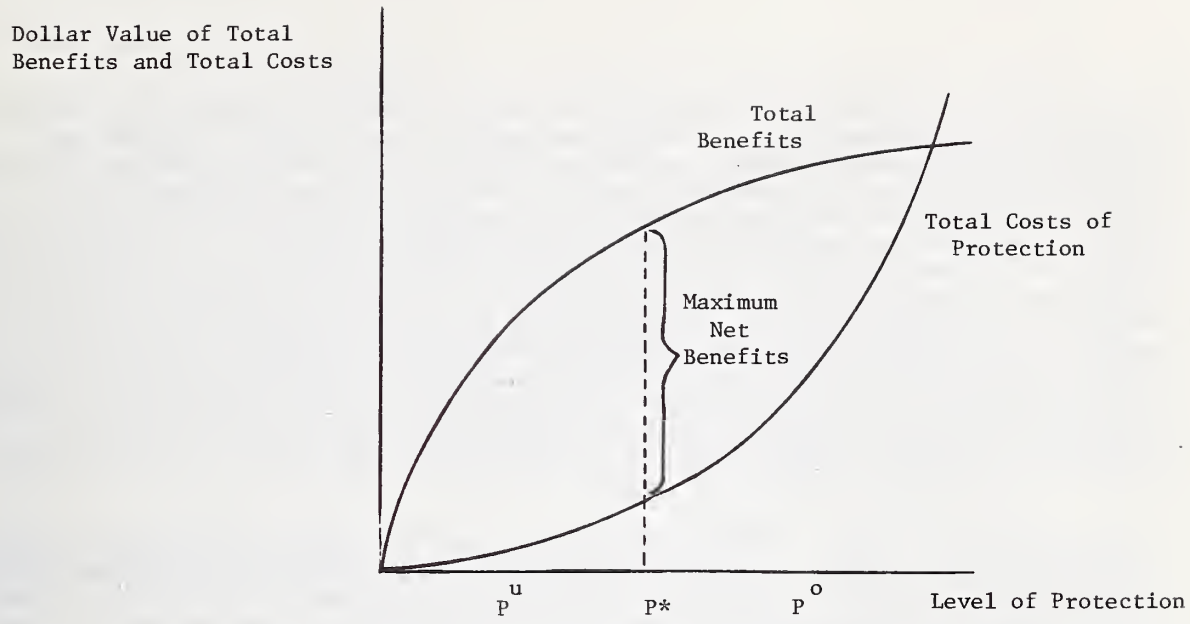

Figure 3.1 Dollar Value of Total Benefits and Total Costs versus level of protection against natural disasters

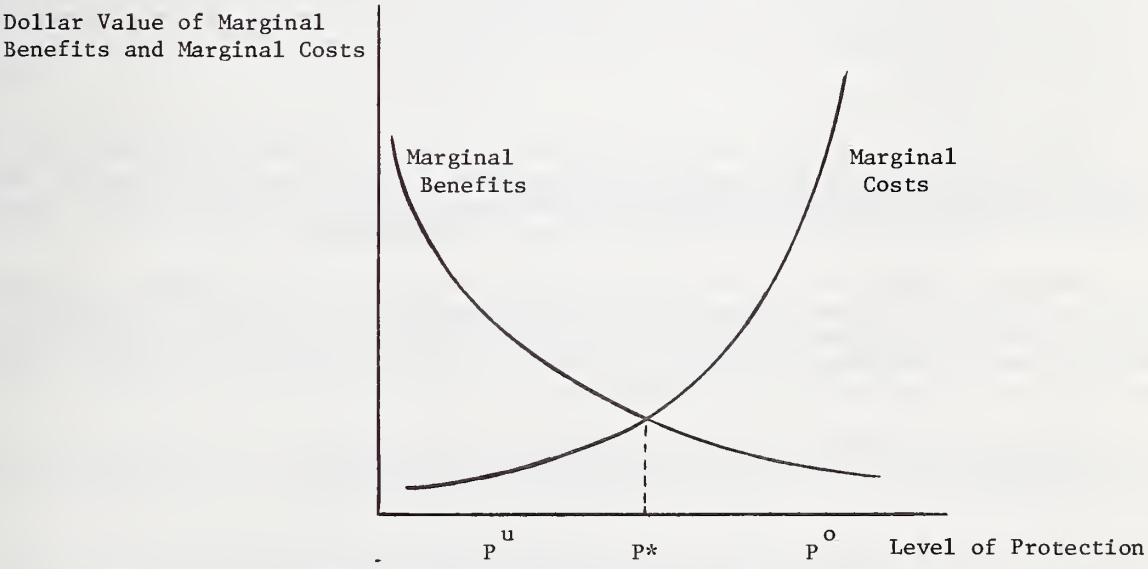

Figure 3.2 Dollar Value of Marginal Benefits and Marginal Costs versus Level of Protection Against Natural Disasters

i.e., maximizes net benefits.[1] This criterion can be restated as choosing that level of protection which equates marginal benefits to marginal costs. Figure 3.1 shows that society's optimal level of disaster protection occurs at P*, where net benefits are maximized. Correspondingly, Figure 3.2 shows that marginal benefits just equal marginal costs of protection at P*.[2] Any level of protection greater than P^*, for example P° in Figures 3.1 and 3.2, indicates that society is over-protecting against disasters. P° represents an inefficient allocation of society's scarce resources. By instituting lower levels of protection (moving toward P*) society's reduction in costs is more than the reduction in benefits. Net benefits will be increased (Figure 3.1) and an equality between marginal benefits and marginal costs will be approached (Figure 3.2). Similarly, any level of protection less than P*, say P^u in Figures 3.1 and 3.2, is a signal that society is under-protecting against natural disasters. By increasing the level of protection from P^u to P*, net benefits increase, marginal benefits approach marginal costs, and a more efficient allocation of resources results. Once P* is achieved no other level of protection will produce a more efficient choice for society.

An equally useful[3] method of determining society's optimal level of protection against natural disasters involves total cost minimization, where total costs are defined to include more than just the costs of protection. Figure 3.3 will be used to illustrate this method. The horizontal axis measures alternative levels of protection (P) and the vertical axis measures the corresponding dollar values (discounted to the present) of costs of protection, total losses, and total costs (costs of protection plus total losses). The costs of protection curve of Figure 3.3 is identical to the total costs of protection curve appearing in Figure 3.1. A total losses curve[4] is shown decreasing at a decreasing rate for increasing levels of protection; i.e., equal increments of protection add successively smaller reductions in losses. Decreasing total losses are vertically added to increasing costs of protection in order to derive a third curve, labeled total costs. Under the cost minimization principle, the optimal level of disaster protection is achieved when total costs (costs of protection plus total losses) are minimized. This is shown to occur at P** in Figure 3.3. The cost minimization method produces a result precisely the same as the benefit-cost method for selecting the optimal level of protection: i.e., P**(Figure 3.3) is equal to P*[5] (Figures 3.1 and 3.2)

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[1]There may be a temptation to do one of the following in a benefit-cost analysis: 1) maximize total benefits or 2) require only that total benefits exceed total costs. The first will cause an inefficient allocation of resources and a non-optimal level of protection. The second will also more than likely cause a non-optimal choice.

[2]Marginal benefits and marginal costs are the additions to total benefits and total costs resulting from a small change in the level of protection. To derive the marginal benefits curve and marginal costs curve we calculate the rate of change in total benefits and total costs at alternative levels of protection. Mathematically, the marginal curves are the first derivatives of the total curves.

[3]Although not referred to as cost minimization, this method can be found in Clifford S. Russell's article "Losses from Natural Disasters," Land Economics, Vol. 46 (November 1970), pp. 383-393.

[4]Note that the total benefits curve previously discussed is derived using the total losses curve. The total benefits curve is merely the total losses curve subtracted from the level of losses incurred in the absence of any protection. See appendix.

[5]See appendix for a mathematical proof of this statement.

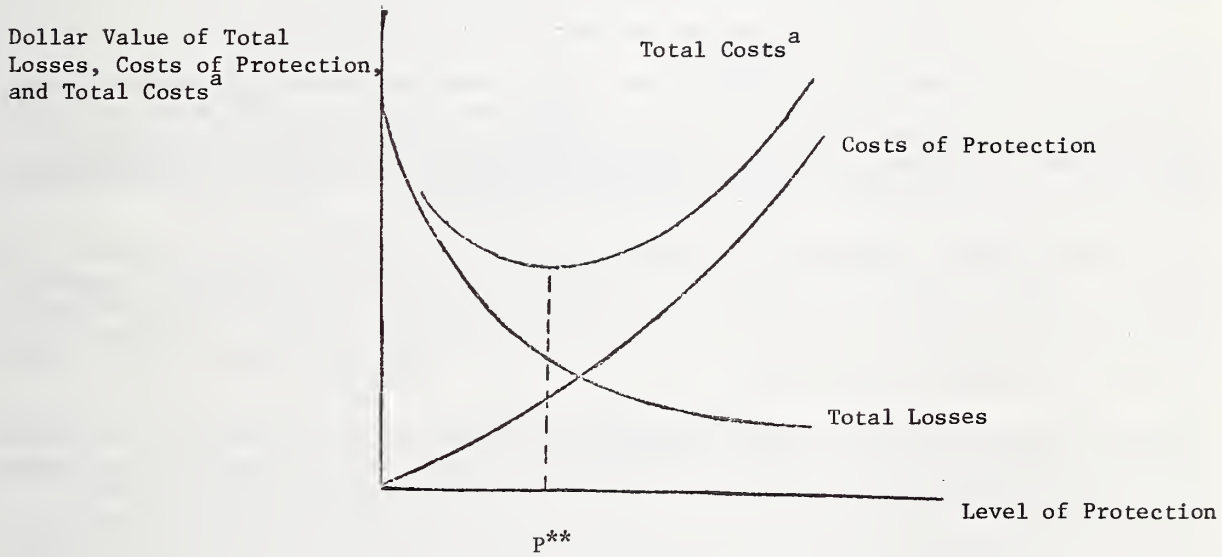

Figure 3.3 Dollar Value of Total Losses, Costs of Protection, and Total Costs[a] versus Level of Protection Against Natural Disasters

[a]Total costs equal costs of protection plus total losses

By protecting at a level greater than P**, costs of protection increase by more than total losses decrease. Total costs (costs of protection plus total losses) increase (a movement upward and to the right occurs along the total costs curve) and are no longer at a minimum. When the level of protection against natural disasters is reduced below P**, total losses increase by an amount greater than the decrease in costs of protection. Again, total costs increase and deviate from the possible minimum. Any level of protection different from P** results in a movement away from minimum total cost and hence a non-optimal level of protection against natural disasters.

In this section we have examined two approaches for determining the optimal level of protection. The level of protection considered in both may be produced by a combination of available techniques or by only one technique of protection. Thus it is emphasized that, when several approaches do in fact exist, they must all be included in the optimization problem; otherwise, an optimal solution may not be achieved.

3.2 Application of Benefit-Cost Analysis to Disaster Mitigation

In this section the essential features of two studies concerned with mitigating the losses from disasters will be discussed. The studies apply two techniques to two different types of problems. The studies reviewed are 1) A Preliminary Study of Engineering Seismology Benefits, and 2) Application of Economic Analyses to Hurricane Warnings to Residential and Retail Activities in the U.S. Gulf of Mexico Coastal Region.

A Preliminary Study of Engineering Seismology Benefits[1] investigates the determination of the economic benefits derived from engineering seismology. The report estimates the economic benefits realized from the passage of the California Field Act. This act was passed by the California State Legislature following the Long Beach earthquake in 1933. It revised the building codes so that all California schools constructed after 1933 would be able to better withstand the effects of earthquakes.

The study compares earthquake damages among schools constructed before the 1933 code revision and schools constructed after (with) the revision. Estimated dollar damages were calculated for 59 schools and four earthquakes. The earthquakes included Imperial Valley (1940), Torrance-Sardina (1941), Kern County (1952), and Daly City (1957). Earthquake magnitudes as measured by the Richter scale were 7.1, 5.4, 7.7, and 5.3 respectively.[2] The dollar damage as a percent of building value at the time of the earthquake was computed for each school. The damage was determined by estimating the cost of restoring a school to its pre-earthquake condition.

Figure 3.4 plots damages as a percentage of building value for different earthquake intensities for schools built prior to 1933 (upper curve) and for schools built later than 1933 (lower curve). For each intensity rating, the curves show the average school damage as a percent of building value. California schools constructed under the earthquake-resistant regulations of the Field Act sustained considerably less damage, as a percent of building

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[1] U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, A Preliminary Study of Engineering Seismology Benefits (Washington, D.C.: Government Printing Office; August 1967).

[2] Ibid., p. 15.

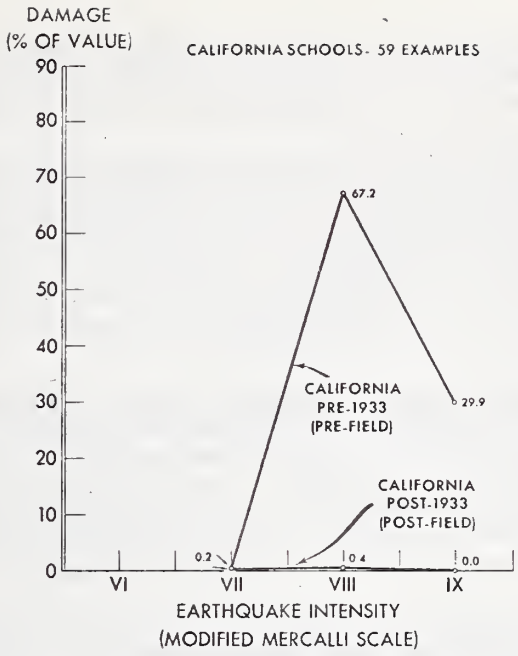

Figure 3.4 —Earthquake damage—California schools.

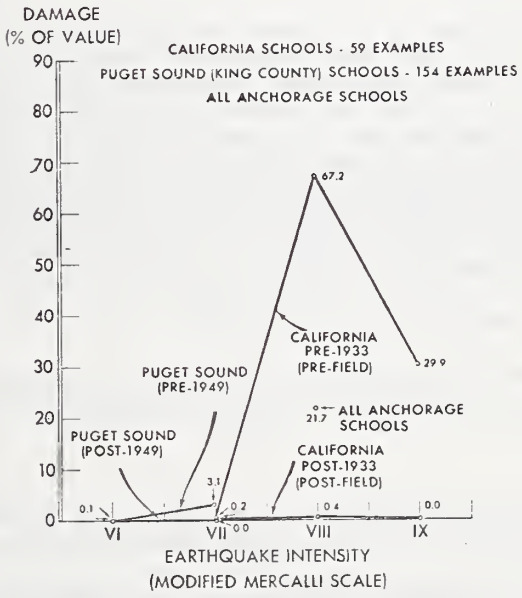

Figure 3.5 —Earthquake damage—California schools, Puget Sound (King County) schools, and Anchorage schools.

value, than schools constructed prior to the code revision.[1] While the former schools experienced an average damage-to-value percentage of 0.4 at an intensity of VIII, the latter schools experienced a 67.2 damage-to-value percentage at the same intensity.

The benefits derived from instituting an earthquake-resistant building code are significant, as Figure 3.4 indicates. However, the costs of code revision have been neglected. Consequently, it has not been determined whether or not the benefits derived from providing earthquake protection through code revision exceed or fall short of the costs for such protection. This, in turn, leads to the question of whether or not society implemented the optimal level of protection against the effects of earthquakes, or whether society is overprotecting (too stringent a code) or underprotecting (in which case a more stringent code should be enforced).

A similar study was conducted for school buildings in Puget Sound, Washington. Damages to school buildings were compared on a pre-1949 and post-1949 construction basis. Since 1949 Seattle has been under the auspices of the Uniform Building Code and a provision for earthquake-resistant construction. As a result, school buildings constructed after 1949 have experienced smaller damages as a percent of their building value than have school buildings constructed before 1949 (see Figure 3.5). The benefits are well defined, but again the social and economic costs of code revision are disregarded in the analysis.

Another empirical study that provides an example of benefit-cost analysis is Application of Economic Analysis to Hurricane Warnings to Residential and Retail Activities in the U.S. Gulf of Mexico Coastal Region.[2] This study applies the principles of game theory to decisions involving improved hurricane prediction and warning systems--a technique of protection against hurricanes. An estimated savings of $15.2 million (as a lower bound estimate) can be realized in the first year from reducing the error of present prediction and warning, according to the study.[3]

People who receive hurricane warnings do not always act rationally. Some do not take protective action against potential effects the storm has on homes and businesses. Anderson and Burnham have calculated the potential savings from averting damages when increased proportions of the population take protective action (Table 3.1). Table 3.2 shows the estimated savings from averting damages when the population grows annually at 5% and an additional 10%, 20%, 60% and 100% of the people who do not take protective action now decide to take protection. Taking year 1 as an example, 20% of the current population presently take protective action when alerted, 80% do not. Let us assume, however, that 10% of the 80% who do not protect now decide to take protective action. Thus, 20% + (10% x 80%) or 28% now take protection. With population growing at an annual rate of 5%, an estimated $3.18 million in damages can be averted. By year 4, when 100% of the new population takes protective action, savings can amount to $13.33 million.

The report also develops a game theory approach to the decision of whether or not to protect. The general model is presented in Figure 3.6. Given the probability (p) of a hurricane

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[1] The reason for the inverse relationship between damage and intensity beyond an intensity of VIII is explained in the report as being caused by variation in sample size.

[2] Lee G. Anderson and John M. Burnham, "Application of Economic Analysis to Hurricane Warnings to Residential and Retail Activities in the U.S. Gulf of Mexico Coastal Region," Monthly Weather Review, February 1973, pp. 126-131.

[3] Ibid., p. 126.

TABLE 3.1

DAMAGE REDUCTION DUE TO INCREASING PERCENT
OF POPULATION PROTECTING AGAINST HURRICANES

Proportion of Alterted Population That Takes Protective Action (%)	Damage Averted ($1,000,000)
20	2.16
40	4.32
60	6.48
80	8.64
100	10.80

Source: Lee G. Anderson and John M. Burnham, "Application of Economic Analysis to Hurricane Warnings to Residential and Retail Activities In the U.S. Gulf of Mexico Coastal Region," Monthly Weather Review. February 1973, p. 127.

TABLE 3.2

DAMAGE REDUCTION WITH POPULATION GROWTH AND INCREASED PROTECTION BY POPULATION

	(1) Percent of Population Now Protecting	(2) Increased Percent of Population Protecting	(3)[a] Percent of New Population Protecting	(4) Population Growth Rate (%)	(5)[b] Damage Averted ($1,000,000)
Year 1	20	10	28	5	3.18
Year 2	20	20	36	5	4.29
Year 3	20	60	68	5	8.50
Year 4	20	100	100	5	13.13

[a] Col. 1 + Col. 2 · (100% - Col. 1).

[b] Col. 3 · $(1.05)^t$ · $10.8 million, where t = 1, 2, 3, 4.

Source: Lee G. Anderson and John M. Burnham, "Application of Economic Analyses to Hurricane Warnings In the U.S. Gulf of Mexico Coastal Region," Monthly Weather Review, February 1973, p. 127.

	Hurricane Strikes	No Hurricane Strikes
Protective Action Taken	$\alpha L + C$	C
No Protective Action Taken	L	0

C = cost of protection

L = dollar losses resulting from a hurricane

α = the proportion of L which cannot be reduced through protective action

Figure 3.6 Hurricane decision matrix

Source: Lee G. Anderson and John M. Burnham, "Application of Economic Analysis to Hurricane Warnings to Residential and Retail Activities In the U.S. Gulf of Mexico Coastal Region," Monthly Weather Review. February 1973, p. 127.

passing over a given area at a given time, then the hurricane forecast should be given only if

$$p(\alpha L + C) + (1-p)C < pL,$$

where C = cost of protection,
L = dollar losses resulting from a hurricane, and
α = the proportion of L which cannot be reduced through protective action.

The left hand side of the inequality represents the expected cost of protecting. The right hand side represents the expected cost of not protecting.

Anderson and Burnham also show that the above expression can be reduced to $p > \frac{C}{(1 - \alpha)L}$. So a forecast warning should not be given unless the probability of the storm striking an area (p) is greater than $\frac{C}{(1 - \alpha)L}$.

The approach can be adapted to the analysis of individual decisions regarding protection against any type of natural disaster. Given the probability of a natural disaster striking, an individual can assess the values of C, L, and α and thus determine whether or not it pays to protect against the potential losses of the disaster. Based on an individual's relative valuation of C, L, and α, it becomes feasible for the individual to protect against the disaster only when $p > \frac{C}{(1 - \alpha)L}$.

4. SUMMARY AND RECOMMENDATIONS

4.1 Summary

An understanding of the relative losses resulting from various types of disasters and individual occurences of disasters is useful to both the individual and society. The individual will be better prepared to assess the potential losses of various disasters and how and to what extent he should protect himself from such losses. Society, in its efforts to mitigate the losses from disasters, will have better information on the basis of which to determine the levels of protection against disasters which maximize net benefits. The following section summarizes and compares the monetary and non-monetary losses associated with the four types of disasters discussed in Chapter 2.[1]

The dollar values of property damages resulting from hurricanes and floods for five-year periods between 1950 and 1969 are shown in Figure 4.1. Comparative damages for tornadoes and earthquakes are shown for five-year periods between 1950 and 1964. Between floods and hurricanes, floods caused the greatest amount of total damages ($7046 million from floods compared to $6008 million from hurricanes). Also, during the period 1950-1954 flooding caused more total property damage than hurricanes, earthquakes, or tornadoes.

Figure 4.2 shows the comparative number of lives lost for the four types of disasters during the period 1950 to 1969. Tornadoes caused the greatest total loss of lives (2,348) and also caused the most deaths in any five-year period.

The decreasing trend in the number of lives lost from disasters in general is not evident in Figure 4.2. The short time period covered or the large five-year intervals may distort the trend other researchers have uncovered.[2] Figure 2.1, Chapter 2 of this report, shows a strong downward trend of lives lost due to hurricanes. This trend, however, is not as apparent for other types of natural disasters.

Assuming that the quality of the statistics reported has not changed significantly between 1969 and 1972, we can compare the relative losses resulting from severe individual disasters. Figures 4.3 and 4.4 show the comparative losses resulting from Hurricane Camille (1969), the Agnes Floods (1973), the San Fernando Earthquake (1971), and the Lubbock, Texas Tornado (1970).

The disaster with the greatest property damages among the four occurences shown in Figure 4.3 was the Agnes Floods ($2,100 million).[3] The number of lives lost during these floods numbered 122. Hurricane Camille took 47% more lives (258) than did the Agnes floods, but caused 32% less property damage ($1,420.7 million).

Figure 4.4 shows the comparative number of dwellings destroyed and damaged by each of the four disasters. Hurricane Camille accounted for 48% of the total number of dwellings destroyed by the four disasters (6013 out of a total of 12,534). The Agnes Floods destroyed 42% or 5,222 of the total dwellings.

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[1] The comparative description of losses from disasters is not as consistent as it might be because of the changing quantity and quality of statistics reported over the years.

[2] See Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters (New York: The Free Press, 1969), p. 7.

[3] The total value of property damages attributed to Tropical Storm Agnes is $3,097.8 million (see Table 2.6, Chapter 2).

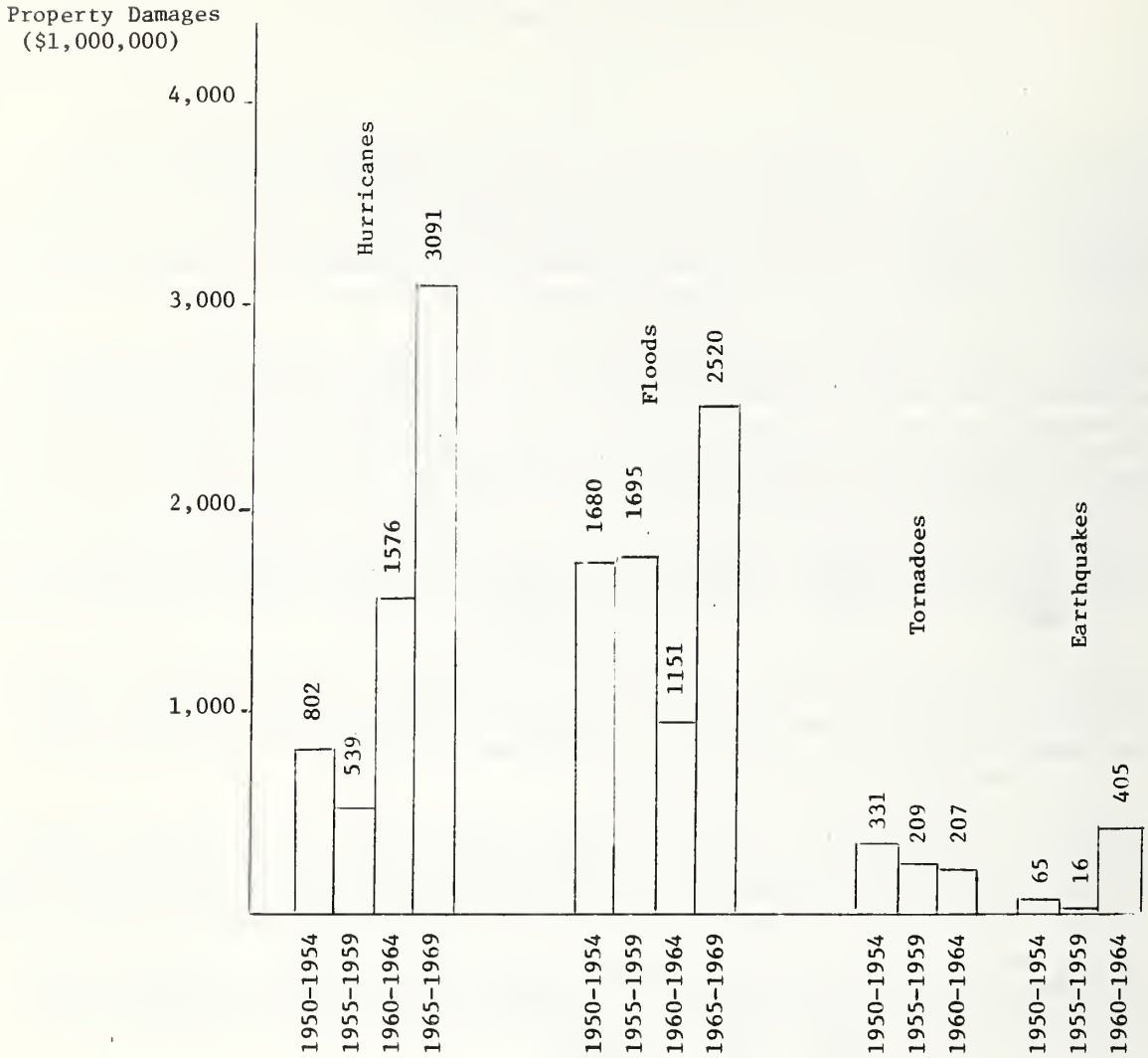

Figure 4.1 Property Damages Resulting from Hurricanes, Floods, Tornadoes and Earthquakes

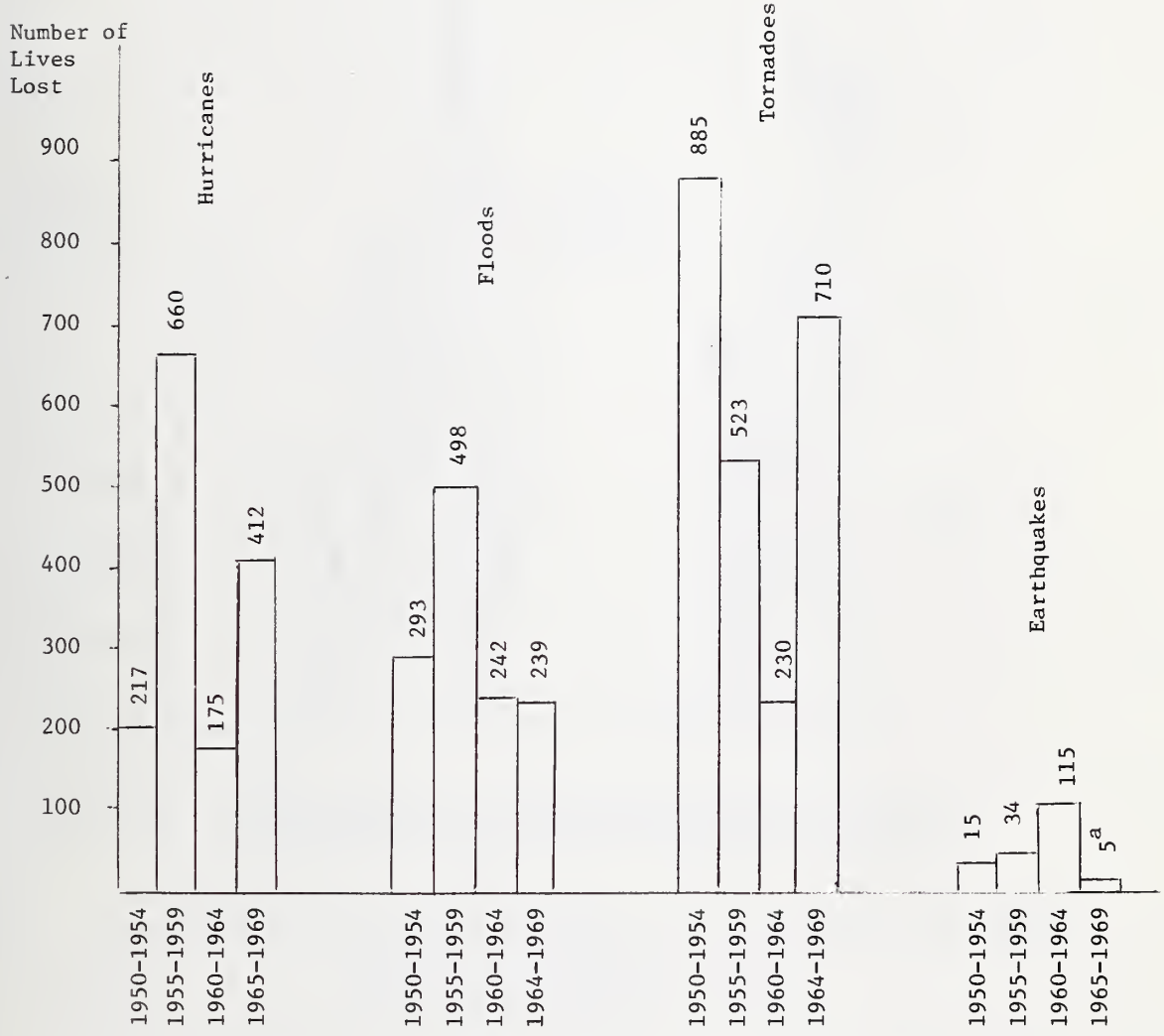

Figure 4.2 Number of lives lost due to hurricanes, floods, tornadoes, and earthquakes

[a]Puget Sound, Washington earthquake only.

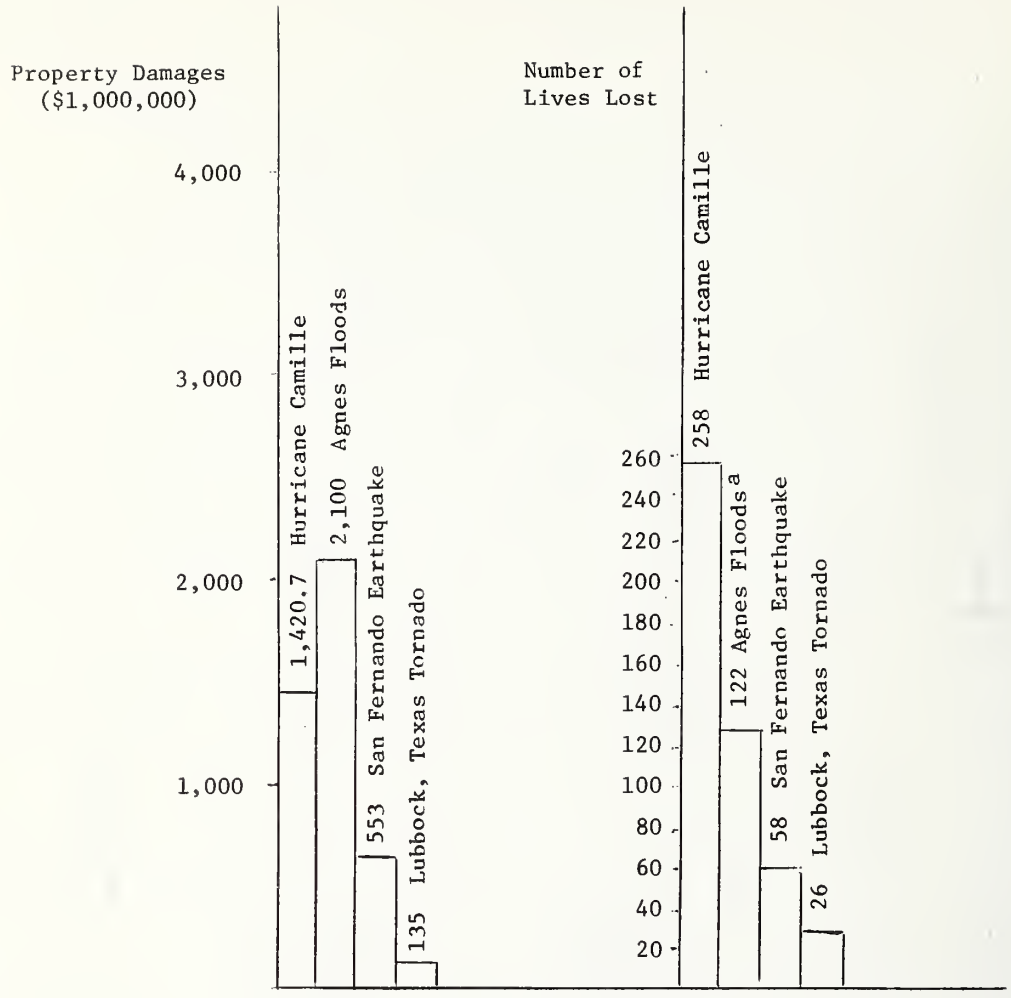

Figure 4.3 Comparisons of property damages and number of lives lost for individual disasters, 1970-1972

[a]Deaths due to hurricane winds and flooding were not reported separately.

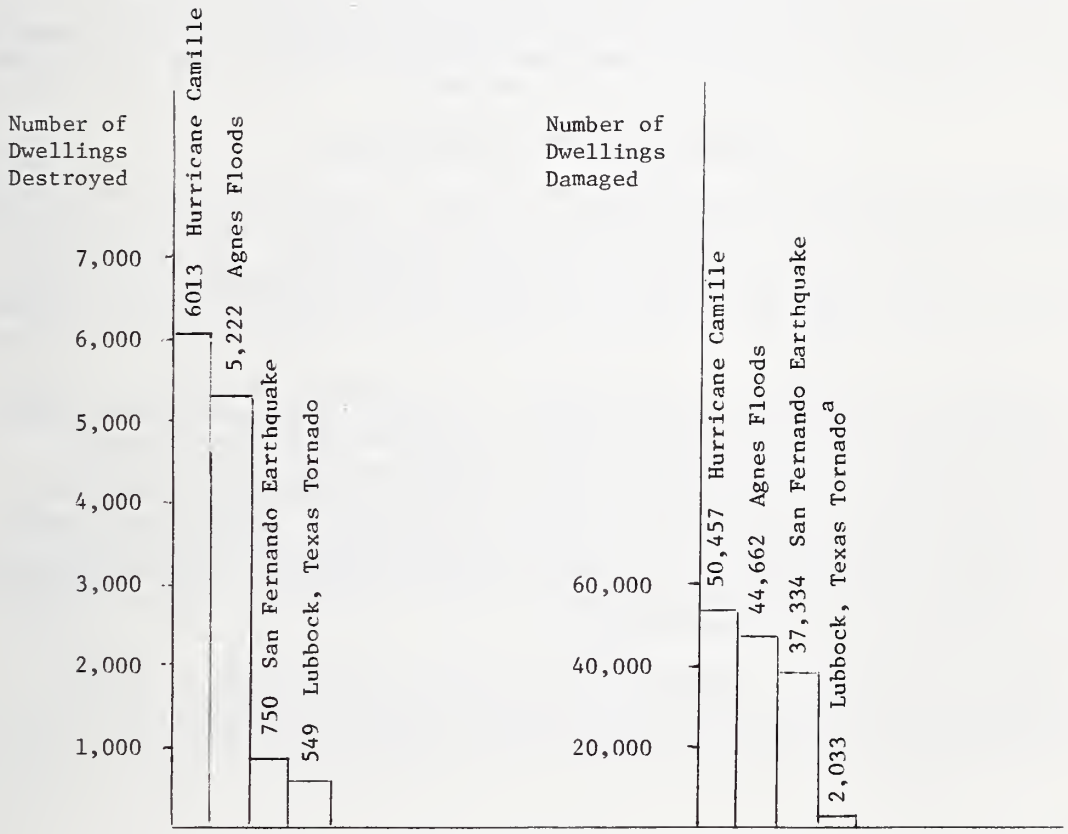

Figure 4.4 Comparisons of number of dwellings destroyed and damaged for individual disasters, 1970-1972

[a]Includes major damage only.

The difference in the number of dwellings damaged by each disaster was small, except for the Lubbock, Texas tornado, which caused damage to only 2,033 dwellings compared to 50,457 by Hurricane Camille, 37,834 by the Agnes Floods, and 44,662 by the San Fernando Earthquake.

If the primary concern in disaster protection is to reduce the dollar property damages and the destruction of dwellings caused by natural disasters, then initial efforts might be directed toward mitigating the effects of hurricanes and floods. These two types of disasters have resulted in relatively higher property damages and destruction of dwellings than have earthquakes and tornadoes. If the concern is for reducing the loss of lives, then it may be more effective to invest in techniques for the mitigation of losses due to tornadoes, which have caused the greatest loss of lives. These conclusions, however, are based on an assessment of the potential benefits (reduction in losses) that might be realized by protecting against the adverse effects of natural disasters, with no examination of the costs of protection. Furthermore, there are various techniques of protection which need to be considered for any analysis of disaster protection.

4.2 Recommendations for Further Research

Additional research is needed to determine the real losses (i.e., in real dollar terms) that individuals and society experience from natural disasters. Research is also necessary to determine 1) the future potential losses which natural disasters pose to various areas of the country and 2) the costs of alternative techniques for protecting against these losses. This additional research knowledge can be used as input for more comprehensive benefit-cost studies of alternative techniques of mitigating losses due to a variety of natural disasters.

Further research is also needed in the investigation of the economics and technology of different techniques of protection against disasters. Shoreline management practices that prevent building in flood-prone areas seem a viable alternative to the conventional engineering structures for reducing hurricane losses along the shoreline.[1] Dwellings can be better protected against flood waters through improved flood-proofing techniques or through location of buildings away from the reach of flood waters. Tornado losses can be reduced by providing better emergency shelters, more accurate prediction and warning systems, and structural modifications of existing and future buildings. Finally, earthquake losses can be reduced through improved earthquake-resistant construction, better land use management, and improved prediction techniques.

Research efforts can be applied to determining the technical effectiveness of disaster resistant provisions in building codes for reducing the losses from disasters. The economic consequences of instituting minimum building standards must be researched. Also, various economic incentives may exist to induce individual homeowners to purchase a given

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[1] For a discussion of present shoreline protection policies and of recommendations to achieve more effective protection, see: U.S. Department of Commerce, National Bureau of Standards, Cost Sharing as an Incentive to Attain the Objectives of Shoreline Protection, by Harold E. Marshall (Washington, D.C.,: Government Printing Office, December 1973).

level of protection against disasters. These incentives must be considered in lieu of or as complementary to building standards.

Although there are numerous techniques available for mitigating the losses from disasters, further research is needed to determine new and better techniques, reliability of existing techniques, improvements in existing techniques, and combinations of techniques that are most economically efficient for mitigating the losses due to natural disasters.

APPENDIX

Economic Efficiency: Maximizing Net Benefits or Minimizing Total Costs (Costs Plus Losses)?

This appendix is a mathematical note to show that minimizing total costs (costs of protection plus total losses) and maximizing net benefits (total benefits minus total costs) are two different techniques for achieving the same outcome--economic efficiency.

Cost minimization (see Figure 3.3) minimizes total costs (C), where total costs are the sum of the costs of protection (c) and total losses (ℓ). Both c and ℓ depend on the level of protection (P) against disasters. Symbolically,

$$c = c(P)$$

and $$\ell = \ell(P),$$

where $$c'(P) > o$$

and $$\ell'(P) < o.$$

Formulating the minimization problem we obtain,

$$\text{MIN } C = c(P) + \ell(P).$$

The first order condition requires that

$$c'(P) + \ell'(P) = o$$

or $$c'(P) = -\ell'(P).$$

Economically speaking, we want to add increments of protection, P, until the increase in costs, c'(P) from the last increment just equals the decrease in losses, $\ell'(P)$.

The efficiency criterion of the benefit-cost method (see Figure 3.1) is to maximize net benefits (B); i.e., total benefits minus total costs. Total costs of protection, c(P), are the same costs of protection that are considered under the cost minimization method. Total benefits are defined as the total losses that would occur (ℓ_o) in the absence of any disaster protection minus the total losses, $\ell(P)$, that occur as the result of protecting at the same level P. Since c(P) and $\ell(P)$ are the same functions as those in the cost minimization method, they also behave the same. Thus $c'(P) > o$ and $\ell'(P) < o$. The maximization problem can now be formulated as follows:

$$\text{MAX } B = [\ell_o - \ell(P)] - c(P).$$

Deriving the first order conditions for maximization we obtain,

$$-\ell'(P) - c'(P) = o$$

or $$c'(P) = -\ell'(P)$$

(since ℓ_o is a constant, its derivative with respect to P is zero).

The conditions for economic efficiency, marginal costs equal to marginal losses, are the same as those under the cost minimization method. However, in the cost-benefit method we choose to call marginal losses marginal benefits since they are derived from total benefits. Furthermore, marginal benefits are merely the negative of marginal losses; i.e.,

$$\frac{d[\ell_o - \ell(p)]}{dP} = - \frac{d\ell(p)}{dP}$$

or $$-\ell'(p) = - \ell'(p) .$$

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This study examines the extent of some of the losses resulting from natural disasters. An estimate of these losses is necessary in order to determine the potential benefits that might be realized from mitigating the negative economic impacts from natural disasters. Absolute and relative losses resulting from hurricanes, floods, earthquakes, and tornadoes are examined. This data will help individuals, communities, and the Federal government make better decisions as to how and what extent protection against disasters should be provided. The application of benefit-cost analysis for choosing the optimal level of protection against disasters is also discussed. Recommendations are made for further research in determining the economic feasibility of various techniques designed to mitigate the losses from disasters.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Benefit-cost analysis; disaster mitigation; earthquakes; economics; efficient; floods; hurricanes; natural disasters; optimal; tornadoes; total cost minimization.

18. AVAILABILITY

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